Engineering Design File

PROJECT NO. 22901

Design for VOC Control for the TSF-09/18 V-Tank Remedial Action

**Idaho National Engineering
and Environmental Laboratory**

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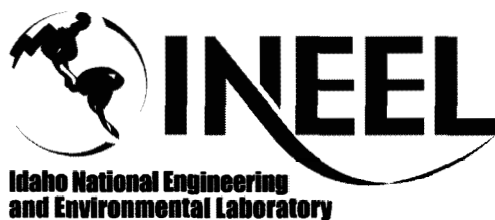
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5. Summary:

This EDF provides the design of an offgas system for the V-Tank remediation. Air stripping calculations provide an estimated stripping rate and average concentration assumed over an approximate 42 hr period. Also, estimated concentrations for PCE, TCA, and TCE over time are provided. Three, 400 lb S-GAC units are required based on conservative design procedures. Estimates of GAC requirements and comparison of gas emissions to industrial hygiene limits are included and show that worker protection will be met. A radionuclide flowsheet and accumulation were also estimated indicating a slow buildup in the scrubber and the first HEPA. The scrubber was evaluated for VOC scrubbing and concluded that although scrubbing occurs, the scrubber only represents a time delay since it is a re-circulating system.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

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DF No.: 4956   EDF Rev. No.: 0   Project File No.: 22901

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ACRONYMS

AEA	AEA Technologies
APAD	Air Permitting Applicability Determination
DCB	Dichloroethylene
DF	Decontamination factor
ER	environmental remediation
ES-CO/R/S	ex situ chemical oxidation/reduction/stabilization
GAC	granular activated carbon
IDLH	Immediate danger to life and health
MTZ	Mass transfer zone
NIOSH	National Institute for Occupational Safety and Health
ORNL	Oak Ridge National Laboratory
OU	operable unit
PCE	Perchloroethylene
RI/FS	Remedial Investigation/Feasibility Study
SCFM	standard cubic feet per minute
S-GAC	Sulfur impregnated granular activated carbon
STEL	Short Term Exposure Limit
SVOC	Semi-volatile organic compound
TCA	Trichloroethane
TCB	Trichlorobenzene
TLV	Threshold limit value
TWA	Time weighted average
VOC	Volatile organic compound

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NOMENCLATURE

A_f	Absorption factor
D	Pipe diameter
F	Friction factor
g_c	Force conversion factor
G	Gas rate, mol/time
H	Dimensionless Henry's constant
$k_L a$	Liquid phase combined mass transfer coefficient
L	Liquid rate, mol/time, pipe length
n	n^{th} plate variable
N_{p+1}	Last plate
P	Pressure
Q	Gas rate, vol/time
Re	Reynolds number
RH	Relative humidity
x	Liquid mol fraction
y	Vapor mol fraction
ΔP	Pressure drop
ρ	Density

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Design for VOC Control for the TSF-09/18 V-Tank Remedial Action

1. SCOPE

The scope of this document includes: (1) Determine appropriate parameters including concentrations and rates for the implementation of granular activated carbon (GAC) for the V-Tank remediation off-gas system; (2) Provide comparisons to industrial hygiene limits for volatile organic carbon (VOCs) and mercury (Hg) emissions; (3) Provide a model to determine appropriate vacuum, flow, and pressure balance in the offgas system; (4) Provide a design for the offgas system; (5) Evaluate the scrubber for scrubbing VOCs; and (6) Provide a radionuclide flowsheet and accumulation diagrams.

2. INTRODUCTION

An accelerated process for the destruction and/or removal of hazardous organic compounds from V-Tank liquids was previously determined to consist of ozonation plus sonication in recirculating flow systems (Ashworth 2004a, 2004b), a process considered to replace the originally proposed process (Fenton's Reagent oxidation). Since then, the equipment associated with a Fenton's Reagent chemical oxidation process at ORNL has become available that is commensurate with the original conceptual design for treating the V-Tank wastes (INEEL 2003)[a]. The sonication system would have been a method for accelerated destruction as the Fenton system was not available. However, the Fenton process current availability changed the scope of the treatment and somewhat changes previous sizing and specification provided in EDF-4602, Rev. 0 (Ashworth 2004b). The scope of this EDF is to only determine parameters for an off-gas system and provide the concentrations, flows, and other information to designers (AEA Technologies) and vendors. This EDF also clarifies the mass transfer relationships and provides a better basis than what was provided in EDF-4602, Rev. 0.

3. BACKGROUND

The four stainless steel tanks (see Figure 1) collectively known as the "V-Tanks" were installed at TAN as part of the system designed to collect and treat radioactive liquid effluents from TAN operations. The V-Tanks are underground stainless steel tanks associated with Operable Unit (OU) 1-10. These four tanks are identified as Tanks V-1, V-2, V-3, and V-9. Tanks V-1, V-2, and V-3 are identical in shape and size. Tank V-9 is smaller and not shaped the same as the other tanks.

Tanks V-1, V-2, and V-3 were used for storage, while Tank V-9 was used as a primary separation tank to separate sediment and sludge from the liquid waste before transferring that waste to V-1, V-2, or V-3. Each of the V-Tanks currently contains a liquid and sludge layer, and all of the V-Tanks lack secondary containment. The tops of Tanks V-1, V-2, and V-3 are approximately 10 ft below grade, while the top of Tank V-9 is approximately 7 ft below grade. Tank V-9 is within Technical Support Facility (TSF) 18, while Tanks V-1, V-2, V-3, are within TSF-09.

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a. The current efforts are to remove VOCs via air stripping. The Fenton oxidation system may be implemented at a later date.

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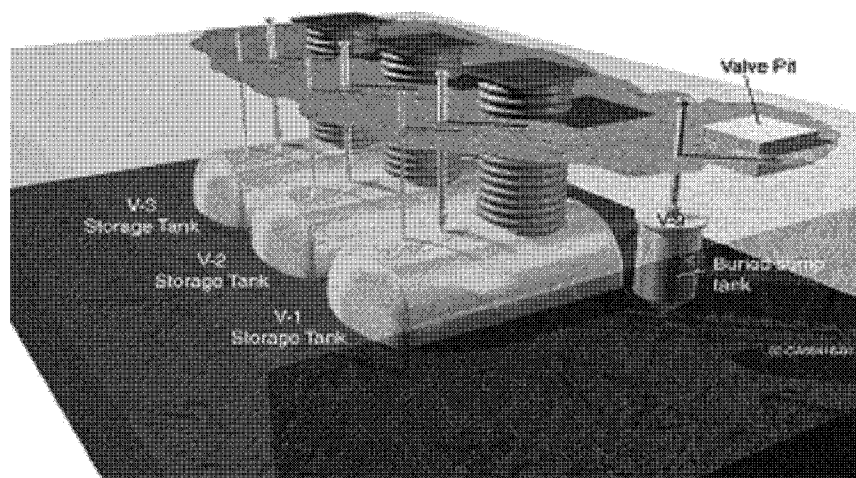
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Figure 1. V-Tank Isometric.

The V-Tanks and associated piping were installed in 1953 and became operational in 1958. The tanks were designed to collect and store liquid radioactive waste at TAN. The waste was stored in the underground tanks and then treated in the evaporator system located in TAN-616. Tanks V-1 and V-3 became inactive in the early 1980s. Tank V-2 was taken out of service in 1968 after a large quantity of oil was discovered in the tank. The oil was removed in 1981. In 1982, the excess free liquid was removed from the V-Tanks. Additional wastewater was reportedly added to Tank V-3 through 1985. Starting in 1985, all low-level radioactive waste at TAN was rerouted to the TAN-666 tanks through a piping modification in the TAN-1704 valve pit. The piping modification stopped intentional discharge to the V-Tanks in 1985. There is no evidence that sludge accumulating in the tanks was removed during or after site operations.

Tanks V-1, V-2, and V-3 are stainless steel tanks measuring 3 m (10 ft) in diameter, 5.9 m (19.5 ft) long, and buried approximately 3 m (10 ft) below ground surface (see Figure 2). The tanks have 50.8-cm (20-in.) manholes that are accessible through 1.8-m (6-ft) diameter culverts installed in 1981. Each tank is equipped with three subsurface influent lines and one subsurface effluent line. The tanks received radioactive wastewater via an influent line from Tank V-9. The remaining influent lines include a caustic line used to neutralize the waste prior to transfer to TAN-616 and a return flow line from the TAN-616 pump room. Tank V-3 has an additional inlet line from the TAN-615 east and west sumps. A single effluent line on each tank is routed to the TAN-616 pump room and evaporator system.

Liquid level measurements, recorded since April 1996, track the fluid levels in V-1, V-2, and V-3. Measurements since 1996, and anecdotal information preceding 1996, indicated an increase in the liquid level in Tank V-3 during the spring. This tank level stopped increasing in 2001. All lines, valves, and drains associated with the TSF-09 tanks are either plugged or identified as inactive; therefore, the increase is believed to be from spring snowmelt and runoff entering the tank through the manway above the entrance to Tank V-3. Liquid level measurements in Tanks V-1 and V-2 have remained relatively constant.

The volume of liquid and sludge in the V-Tanks has been estimated based on the results of the 1996 RI/FS sampling. Table 1 summarizes the capacities and current contents (i.e., reflecting liquid level increases since the RI/FS) of the four V-Tanks.

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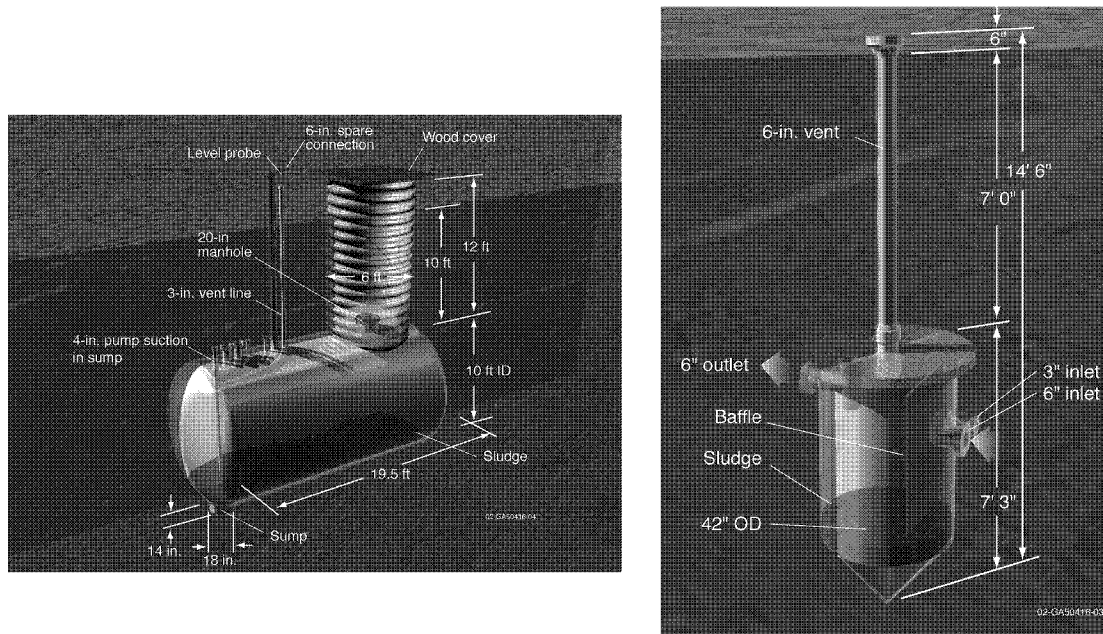
Figure 2. Tanks V-1, V-2, V-3, and V-9 (right).

Table 1. V-Tank Capacities and Current Contents (gallons).

Tank	Capacity	Sludge Mass (kg)	Sludge Volume	Liquid Volume	Total Volume
V-1	10,000	2,001	520	1,164	2,521
V-2	10,000	1,769	458	1,138	2,227
V-3	10,000	2,512	652	7,661	3,164
V-9	400	1,065	250	70	1,315
Total	30,400	7,348	1,880	10,033	11,913

A pre-conceptual design study addressed seven possible alternatives for remediating the V-Tanks and treating the contaminants. A subsequent Technical Evaluation study selected ex-situ chemical oxidation/reduction/stabilization (ES-CO/R/S) as the preferred remediation technology. Subsequently, a Vconceptual design report, Conceptual Design Report for Ex Situ Chemical Oxidation/Reduction and Stabilization of the V-Tanks at Waste Area Group 1, Operable Unit 1-10, INEEL /EXT-03-00438, June 2003, was written (INEEL 2003). The current waste treatment process is a Fenton Reagent, oxidation process, provided by AEA Technologies (AEA) to oxidize polychlorinated biphenyls (PCBs). A schematic of this process is shown in Figure 3. The basic process steps are discussed in Section 5 and the assumptions are discussed in Section 5.1. Requirements for the design are provided in the technical and functional requirements (INEEL 2000a/b).

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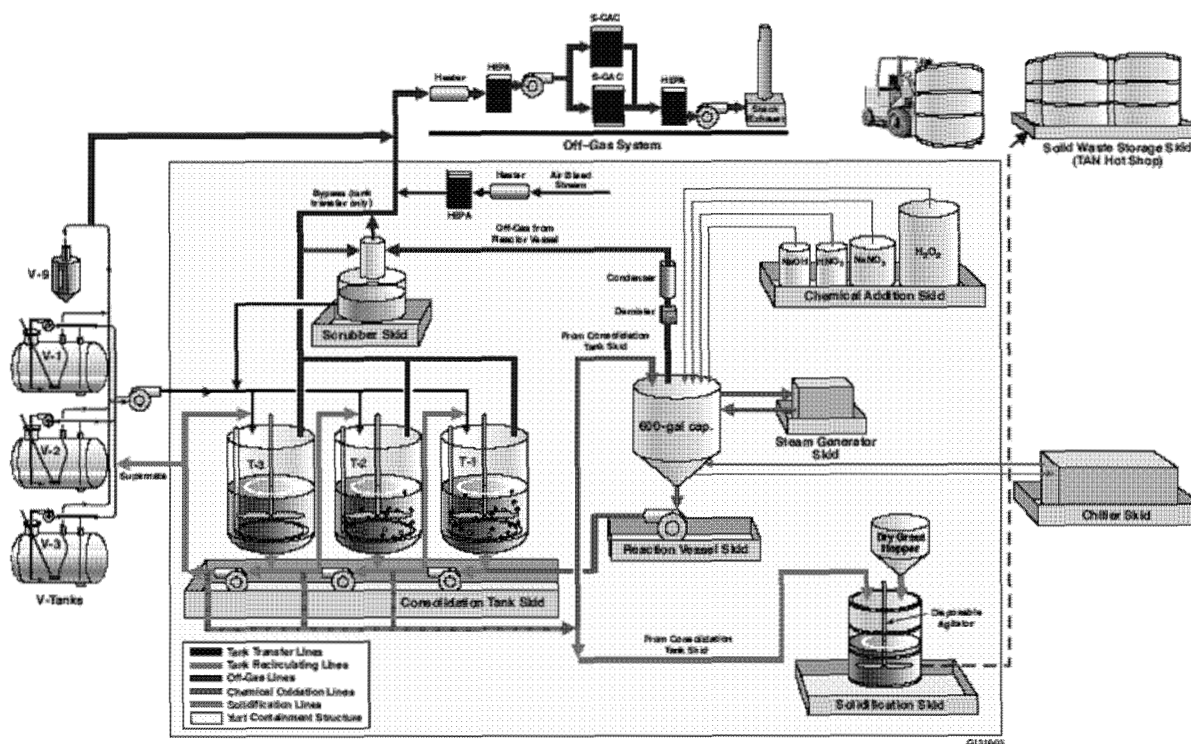
Figure 3. Process Schematic.

4. V-TANK WASTE CHARACTERIZATION

The feed stream to the V-tank treatment system consists of a composite waste stream that includes the V-tank contents (Tanks V-1, V-2, V-3, and V-9) with the additional waste streams given in Table 2. There was a decision by the project to co-mingle these waste streams with the V-tank waste for treatment. [Note: These waste streams are roughly 1 to 2 wt% of the V-tanks waste.] The data for the V-tanks waste is provided in Tyson 2003. The data for the composite waste stream is provided in Tyson 2004.

To determine the applicable VOCs from the composite waste, the data from the two aforementioned characterization reports (Tyson 2003, Tyson 2004) needed to be filtered. Note that this EDF characterization may not match other documents due to the inherent conservatism needed to obtain weighted average concentrations and provide conservative estimates at the 95% confidence interval. The prescription used was to retain any component that had a "detect" in a given sample for any of the waste streams, regardless of phase. For a given component, this was computed at the 95% confidence level of a weighted average using the Microsoft Excel function TINV (probability, degrees of freedom). The basic algorithm for filtering data was initially done for the V-tanks (in Revision 0 of this EDF) and is shown in Figure 4. This algorithm can be extended to all of the waste streams that make up the composite. As expected, this method provides conservative values for the concentrations.

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Table 2. Miscellaneous Streams.

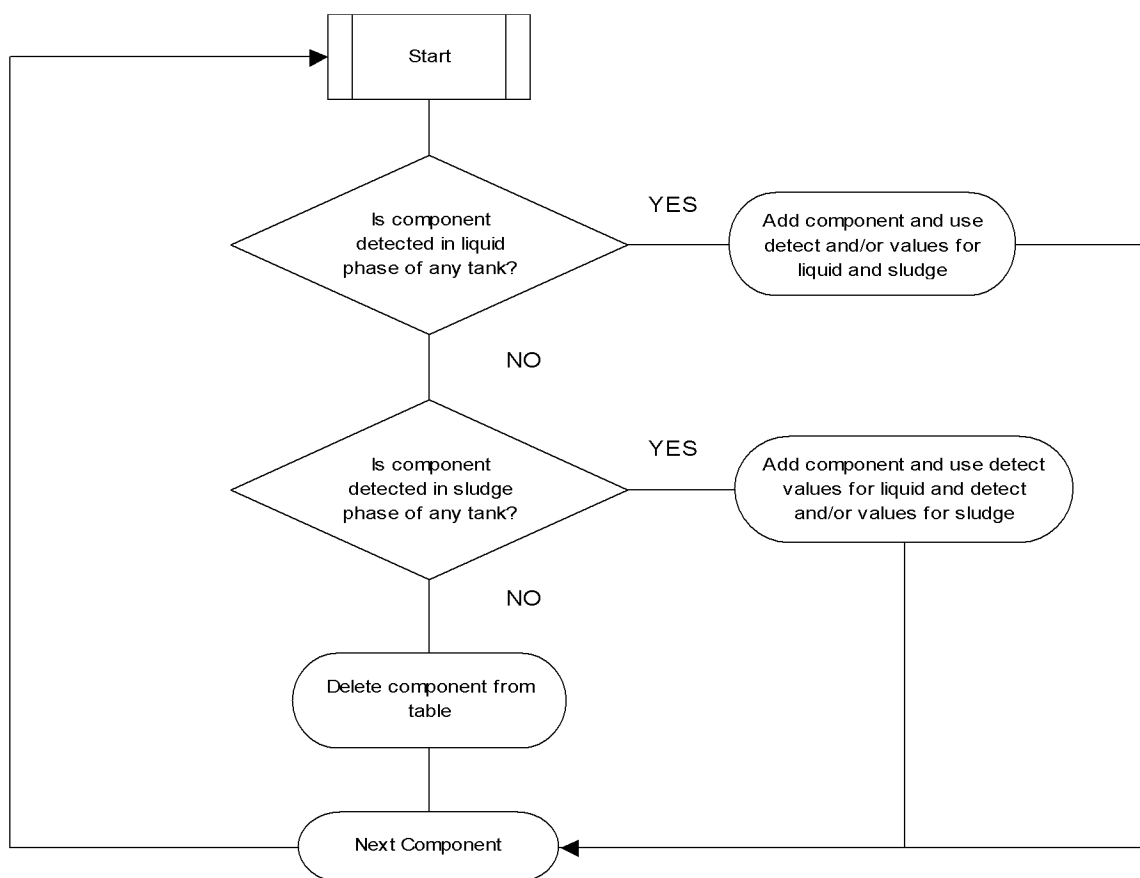| Waste Stream	Volume	Adjusted Volume (gal)	Rationale for Inclusion into V-Tank Treatment Unit
ARA 16	80 gallons	380	Agency agreement
			Waste stream similarity
			No designated treatment process
Unaltered V-tank samples	<50 gallons	50	Return of V-tank samples to point of origin
OU 1-07B sludges	4 gallons	15	CERCLA waste that originated form the V-tanks prior to injection well discharge and subsequent retrieval
Liquids removed from isolating piping form TAN-616 to V-1, V-2, V-3 and V-9	3 carboys (5-gal) 1 Drum (30-gal)	20	Waste was in V-tank feed lines

Figure 4. Characterization Flowchart.

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The results of this filter are provided in Tables 3, 4, 5, and 6 for organic compounds, inorganics, radionuclides[b], and individual V-tank VOCs (used for estimating gas concentrations during consolidation operations), respectively. The values in these tables are the 95% confidence levels based on the weighted averages to provide more conservatism in the design.

Table 3. Organic Compounds Based on Figure 1.

Composite V-Tanks VOC @95%UCL

Constituent	Sludge Conc. mg/kg	Liquid Conc. mg/L	Total Conc. mg/kg	Sludge Mass kg	Liquid Mass kg	Total Mass kg
Acetone	2.35E+01	0.00E+00	3.84E+00	1.76E-01	0.00E+00	1.76E-01
Benzene	1.22E-03	0.00E+00	1.99E-04	9.14E-06	0.00E+00	9.14E-06
bromomethane	2.63E+01	6.27E-01	4.81E+00	1.97E-01	2.41E-02	2.21E-01
Carbon disulfide	8.25E-04	0.00E+00	1.34E-04	6.17E-06	0.00E+00	6.17E-06
Chlorobenzene	3.71E-04	0.00E+00	6.05E-05	2.78E-06	0.00E+00	2.78E-06
Chloroethene (vinyl chloride)	8.63E+01	1.04E+00	1.49E+01	6.46E-01	3.99E-02	6.86E-01
chloromethane	1.62E+01	1.07E-01	2.72E+00	1.21E-01	4.10E-03	1.25E-01
1,2-dichlorobenzene	6.19E+01	3.38E+00	1.29E+01	4.63E-01	1.30E-01	5.93E-01
1,3-dichlorobenzene	8.47E+01	3.44E+00	1.67E+01	6.34E-01	1.32E-01	7.66E-01
1,4-dichlorobenzene	8.92E+01	3.44E+00	1.74E+01	6.68E-01	1.32E-01	8.00E-01
1,1-dichloroethane	2.14E+01	3.32E-01	3.77E+00	1.60E-01	1.27E-02	1.73E-01
cis-1,2-Dichloroethene	8.95E+00	4.84E-03	1.46E+00	6.70E-02	1.86E-04	6.72E-02
trans-1,2-dichloroethylene	3.71E+01	5.76E-01	6.54E+00	2.78E-01	2.22E-02	3.00E-01
1,1-Dichloroethene	7.67E+00	1.74E-02	1.26E+00	5.74E-02	6.67E-04	5.81E-02
Ethylbenzene	7.67E-01	0.00E+00	1.25E-01	5.74E-03	0.00E+00	5.74E-03
methylene chloride	1.05E+02	1.15E+00	1.81E+01	7.87E-01	4.42E-02	8.31E-01
4-Methyl-2-pentanone	1.95E-04	0.00E+00	3.17E-05	1.46E-06	0.00E+00	1.46E-06
Tetrachloroethylene (PCE)	1.46E+03	1.37E+00	2.39E+02	1.09E+01	5.26E-02	1.10E+01
Styrene	2.87E-04	0.00E+00	4.68E-05	2.15E-06	0.00E+00	2.15E-06
1,1,2,2-Tetrachloroethane	6.50E-01	0.00E+00	1.06E-01	4.86E-03	0.00E+00	4.86E-03
Toluene	8.70E+00	5.29E-03	1.42E+00	6.51E-02	2.03E-04	6.53E-02
1,2,4-Trichlorobenzene	8.57E+01	3.43E+00	1.68E+01	6.41E-01	1.32E-01	7.73E-01
1,1,2-Trichloroethane	4.67E-01	2.08E-02	9.35E-02	3.49E-03	7.99E-04	4.29E-03
1,1,1-Trichloroethane (TCA)	6.60E+02	3.59E+00	1.11E+02	4.94E+00	1.38E-01	5.08E+00
Trichloroethylene (TCE)	4.62E+03	8.22E+00	7.60E+02	3.46E+01	3.16E-01	3.49E+01
xylene	3.34E+00	0.00E+00	5.45E-01	2.50E-02	0.00E+00	2.50E-02

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b. Some of the radionuclides had no values for V-9 so the highest from the set was used.

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Table 3. (continued).

Composite V-Tanks VOC @95%UCL

Constituent	Sludge Conc. mg/kg	Liquid Conc. mg/L	Total Conc. mg/kg	Sludge Mass kg	Liquid Mass kg	Total Mass kg
Aroclor-1254	9.84E-02	0.00E+00	1.61E-02	7.37E-04	0.00E+00	7.37E-04
Aroclor-1260	1.31E+02	3.44E-01	2.17E+01	9.82E-01	1.32E-02	9.96E-01
Benzo[b]fluoranthene	2.56E-02	0.00E+00	4.17E-03	1.91E-04	0.00E+00	1.91E-04
Benzoic Acid	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
bis(2-ethylhexyl)phthalate	3.38E+03	1.41E-01	5.51E+02	2.53E+01	5.41E-03	2.53E+01
4-Chloro-3-methylphenol	3.30E-02	0.00E+00	5.38E-03	2.47E-04	0.00E+00	2.47E-04
Dibenz[a,h]anthracene	3.19E-02	0.00E+00	5.21E-03	2.39E-04	0.00E+00	2.39E-04
2,4-dimethylphenol	1.02E+02	3.44E+00	1.95E+01	7.62E-01	1.32E-01	8.94E-01
di-n-butylphthalate	8.56E+01	3.44E+00	1.68E+01	6.40E-01	1.32E-01	7.72E-01
4,6-dinitro-2-methylphenol	4.68E+02	3.52E+00	7.93E+01	3.50E+00	1.35E-01	3.64E+00
di-n-octylphthalate	9.44E+01	3.44E+00	1.83E+01	7.06E-01	1.32E-01	8.38E-01
2-methylnaphthalene	3.07E+01	3.44E+00	7.89E+00	2.30E-01	1.32E-01	3.62E-01
2-methylphenol	1.19E+02	3.45E+00	2.24E+01	8.93E-01	1.32E-01	1.03E+00
4-methylphenol	1.01E+02	3.45E+00	1.94E+01	7.59E-01	1.32E-01	8.91E-01
naphthalene	8.17E+01	3.44E+00	1.62E+01	6.11E-01	1.32E-01	7.43E-01
4-nitrophenol	4.68E+02	3.52E+00	7.93E+01	3.50E+00	1.35E-01	3.64E+00
N-Nitroso-di-n-propylamine	4.53E-02	0.00E+00	7.38E-03	3.39E-04	0.00E+00	3.39E-04
phenanthrene	8.51E+01	3.44E+00	1.68E+01	6.37E-01	1.32E-01	7.69E-01
phenol	8.84E+01	3.44E+00	1.73E+01	6.61E-01	1.32E-01	7.94E-01
pyrene	9.43E+01	4.56E-01	1.58E+01	7.05E-01	1.75E-02	7.23E-01
Total Carbon (TOC)	1.07E+05	6.02E+01	1.76E+04	8.03E+02	2.32E+00	8.06E+02
tributyl phosphate	0.00E+00	1.05E-02	8.75E-03	0.00E+00	4.02E-04	4.02E-04

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Table 4. Inorganic Compounds Based on Figure 1.

Composite V-Tanks Inorganic @95%UCL

Constituent	Sludge Conc. mg/kg	Liquid Conc. mg/L	Total Conc. mg/kg	Sludge Mass kg	Liquid Mass kg	Total Mass kg
Ag	1.44E+02	1.25E-02	2.35E+01	1.08E+00	4.81E-04	1.08E+00
Al	3.87E+03	1.05E+00	6.32E+02	2.90E+01	4.03E-02	2.90E+01
As	3.14E+00	1.63E-02	5.25E-01	2.35E-02	6.25E-04	2.41E-02
B	2.23E+01	1.26E+01	1.42E+01	1.67E-01	4.85E-01	6.52E-01
Ba	1.54E+02	6.72E-01	2.57E+01	1.15E+00	2.58E-02	1.18E+00
Be	9.04E+00	8.44E-02	1.54E+00	6.77E-02	3.24E-03	7.09E-02
Bromide	9.28E+00	2.81E+00	3.87E+00	6.95E-02	1.08E-01	1.77E-01
Ca	9.52E+03	4.78E+01	1.59E+03	7.13E+01	1.84E+00	7.31E+01
Cd	1.80E+01	4.60E-02	2.97E+00	1.35E-01	1.77E-03	1.36E-01
Chloride	2.02E+02	1.29E+02	1.41E+02	1.51E+00	4.97E+00	6.48E+00
Co	2.54E+00	1.25E-01	5.19E-01	1.90E-02	4.81E-03	2.38E-02
Cr	2.44E+03	8.59E-02	3.98E+02	1.83E+01	3.30E-03	1.83E+01
Cu	1.49E+02	9.40E-02	2.44E+01	1.11E+00	3.61E-03	1.12E+00
Fe	2.18E+04	1.87E+00	3.56E+03	1.63E+02	7.18E-02	1.64E+02
Fluoride	5.53E+00	1.72E+01	1.53E+01	4.14E-02	6.62E-01	7.03E-01
Hg	5.84E+02	5.47E-02	9.53E+01	4.37E+00	2.10E-03	4.37E+00
K	2.38E+03	2.42E+02	5.90E+02	1.78E+01	9.29E+00	2.71E+01
Mg	1.28E+04	2.21E+01	2.11E+03	9.58E+01	8.49E-01	9.67E+01
Mn	5.99E+03	1.39E+00	9.78E+02	4.49E+01	5.32E-02	4.49E+01
Na	6.37E+02	3.01E+02	3.56E+02	4.77E+00	1.16E+01	1.63E+01
Ni	1.25E+02	5.14E-01	2.08E+01	9.34E-01	1.98E-02	9.53E-01
Nitrate	1.09E+01	1.07E+00	2.68E+00	8.17E-02	4.13E-02	1.23E-01
Nitrite	4.86E+00	1.38E+01	1.23E+01	3.64E-02	5.29E-01	5.65E-01
P	5.77E+04	1.39E+00	9.41E+03	4.32E+02	5.36E-02	4.32E+02
Pb	2.72E+02	1.85E-01	4.45E+01	2.04E+00	7.12E-03	2.04E+00
Phosphate	1.06E+01	6.40E+00	7.09E+00	7.93E-02	2.46E-01	3.25E-01
Sb	8.74E+00	2.22E-01	1.61E+00	6.54E-02	8.54E-03	7.40E-02
Se	3.00E+00	1.70E-02	5.04E-01	2.25E-02	6.54E-04	2.31E-02
Si	9.73E+04	9.37E+00	1.59E+04	7.28E+02	3.60E-01	7.29E+02
Sn	1.38E+01	9.17E-03	2.25E+00	1.03E-01	3.52E-04	1.03E-01
Sulfate	3.74E+02	2.49E+01	8.18E+01	2.80E+00	9.55E-01	3.76E+00
Tl	2.11E+01	3.50E-02	3.47E+00	1.58E-01	1.34E-03	1.59E-01
V	2.39E+00	1.65E-01	5.27E-01	1.79E-02	6.34E-03	2.42E-02
Zn	1.63E+03	8.26E+00	2.72E+02	1.22E+01	3.17E-01	1.25E+01

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Table 5. Radionuclides Based on Figure 1.

Composite V-Tanks Radionuclides @95%UCL

Radionuclide	nCi/g	nCi/mL	nCi/g	Ci Sludge	Ci Liquid	Total Ci
Ag-108m	1.00E+00	3.58E-03	1.66E-01	7.50E-03	1.38E-04	7.64E-03
Am-241	9.16E+00	5.86E-04	1.49E+00	6.86E-02	2.25E-05	6.86E-02
Cm-242	3.87E-02	2.16E-05	6.32E-03	2.89E-04	8.29E-07	2.90E-04
Cm-243/244	2.40E+00	8.24E-05	3.91E-01	1.79E-02	3.17E-06	1.79E-02
Co-60	3.97E+02	3.59E-02	6.48E+01	2.97E+00	1.38E-03	2.97E+00
Cs-134	1.43E+00	3.23E-03	2.36E-01	1.07E-02	1.24E-04	1.08E-02
Cs-137	7.35E+03	1.09E+01	1.21E+03	5.50E+01	4.21E-01	5.55E+01
Eu-152	2.00E+01	1.45E-02	3.27E+00	1.50E-01	5.57E-04	1.50E-01
Eu-154	3.13E+01	4.84E-03	5.10E+00	2.34E-01	1.86E-04	2.34E-01
Eu-155	3.47E+00	1.24E-02	5.75E-01	2.59E-02	4.78E-04	2.64E-02
Ni-63	1.01E+03	2.60E-01	1.64E+02	7.53E+00	9.98E-03	7.54E+00
Np-237	3.17E-02	1.24E-04	5.27E-03	2.37E-04	4.77E-06	2.42E-04
Pu-238	1.53E+01	2.34E-03	2.50E+00	1.15E-01	9.01E-05	1.15E-01
Pu-239/240	8.56E+00	6.72E-04	1.40E+00	6.40E-02	2.58E-05	6.40E-02
Ra-226	2.42E-01	0.00E+00	3.94E-02	1.81E-03	0.00E+00	1.81E-03
Sr-90	1.55E+04	1.35E+01	2.55E+03	1.16E+02	5.19E-01	1.17E+02
U-233/234	5.17E+00	2.10E-02	8.60E-01	3.87E-02	8.07E-04	3.95E-02
U-235	1.66E-01	6.86E-04	2.76E-02	1.24E-03	2.64E-05	1.27E-03
U-238	9.01E-02	2.05E-04	1.49E-02	6.74E-04	7.88E-06	6.82E-04
Zn-65	1.89E-01	0.00E+00	3.09E-02	1.42E-03	0.00E+00	1.42E-03
Tritium	5.17E+01	2.52E+01	2.95E+01	3.87E-01	9.67E-01	1.35E+00
Th-228	4.83E-05	0.00E+00	7.87E-06	3.61E-07	0.00E+00	3.61E-07
Th-230	1.77E-05	0.00E+00	2.89E-06	1.33E-07	0.00E+00	1.33E-07
K-40	3.71E-04	0.00E+00	6.05E-05	2.78E-06	0.00E+00	2.78E-06

Table 6. Individual Tank Liquid concentrations of Key Components.

	V-Tank Liquid Compositions @95%UCL, mg/L			
Constituent	V-1	V-2	V-3	V-9
PCE	2.11E-01	4.18E-02	4.16E-02	7.29E+01
TCA	4.18E-02	4.18E-02	4.16E-02	1.80E+02
TCE	2.41E-01	4.52E-01	3.00E-01	6.36E+02
Hg	4.02E-01	4.18E-03	4.16E-03	0.563

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5. OFF-GAS SYSTEM DESIGN

5.1 Assumptions and Uncertainties

- During sparging, up to all of the 56.4 kg of VOCs (the estimated amount based on 95% confidence limit concentrations) in both the supernate and the sludge might be sparged out of the liquid and sludges, depending on the actual mass tranfer and volatilization during sparging. None of the 42 kg of SVOCs (95% confidence limit) or the TOC (assumed to include cutting oil, etc) is assumed to volatilize from the supernate or sludge during sparging. Volatilization of SVOCs was shown to be very small in Appendix A calculations. If SVOCs or other TOCs do volatilize during sparging, then these sparged species will tend to sorb on the carbon with efficiencies at least as high as the VOCs. The estimated loading on the carbon bed could be much higher than calculated based on the VOCs alone.

- It is assumed that the liquid-phase mass transfer coefficient ($k_L a$) from Perry's Handbook (Perry and Green 1984) applies to air stripping this particular waste. There is an uncertainty associated with this assumption as no actual testing has been done. However, the literature[c] indicates that the mass transfer coefficient $k_L a$ is in fact on the order suggested, and the solid-liquid transfer resistance of contaminants in the sludge to the supernate is small compared to the predicted $k_L a$ for small particle sizes.

- Stripping of essentially all of the VOC components from the consolidation tanks during air spargingcan take several days. However, the sparge duration to strip essentially all of the PCE, TCA, and TCE is predicted to be 42 hours/tank, based on the longest estimated sparge duration (for TCE). Some of the other VOCs[d], with low Henry's law constants, take much longer. If significant quantities of those VOCs exist in the supernate or the sludge, much of it would remain after sparging[e] for only 42 hours[f]. However, dichlorobenzene is not present in significant amounts compared to PCE, TCA, and TCE, and the estimated small amount of total dichlorobenzenes is based on detection limit values. Actual levels of dichlorobenzenes, and other species, in the V-Tanks are probably lower than estimated in Table 3.

- During sparging, the more volatile components will volatilize out of the liquid faster, at higher concentrations in the air. The VOC concentrations in the sparge air will decrease as the VOCs in the liquid become more depleted. Also, without testing, if the mass transfer coefficient $k_L a$ is much lower than the literature suggests, it could take longer than 42 hours to strip the VOCs. However, the literature indicates that it will be faster rather than slower.

- It is assumed that the DF across the GAC bed is 200 for all components. The IDLH should not be exceeded even if the assumption is wrong for any of the components.

- The air in-leakage to the consolidation tanks is assumed to be 1 scfm.

- Spent carbon from the carbon bed that will contain sorbed VOCs and potentially some radionuclide contamination, can be disposed of safely and at reasonable cost at Envirocare (or other permitted facility if treatment is required) or the INEEL CERCLA Disposal Facility (ICDF).

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c. See Appendix B.

d. e.g., dichlorobenzene

e. Dichlorobenzene and some others are artifacts of the characterization prescription and are questionable as to their presence.

f. 42 hours is a nominal value, actual predictions are time less for 99% removal

- The initial VOC and Hg concentrations of the V-Tanks were assumed at equilibrium with the liquid phase.

- The mercury is the volatile, elemental form. If it is in a form that is soluble in water, such as HgCl, or in a less volatile form, then much less of the mercury would sparge at a much slower rate, and more mercury would remain in the supernate or sludge after sparging for VOC removal is complete.

- The entrainment functions from Perry's (Perry 1963) applies to air stripping even though they are based on evaporation.

- Other assumptions as discussed in the rest of the EDF and in Appendix A.

5.2   Process Design

Several options were considered to provide VOC and Hg control during the remedial action. VOC control options that were considered included thermal oxidation, thermal desorption followed by condensation, and sorption (DOE 2002, INEEL 2002). The initial off-gas system conceptual design for the initial ex situ chemical oxidation, reduction, and stabilization design included fixed bed activated carbon sorption for VOCs and Hg (Raivo 2003).

The current process design for the remedial action off-gas system is shown in Figure 5. The material and energy balances are shown in Table 8. Only one offgas system will be used, for both the V-tank vent system and consolidation tank sparging. Dampers will isolate one system from the other. The remedial action will include 3 separate steps or phases during which VOC, PCB, Hg, and radionuclide emissions must be controlled:

- Transfer of V-Tank Contents to the Consolidation Tanks

- Consolidation Tank Sparging

- ExSitu Chemical Oxidation/Reduction, e.g., Fenton Process (to be designed for at a later date).

5.2.1   Consolidation

The first step of the remedial action is to transfer the contents of the V-Tanks to the consolidation tanks. This transfer will be done by first transferring the Tank-V3 supernatant to one of the consolidation tanks for later use in flushing other tanks. Then each of the other V-tanks will be pumped to one of the other consolidation tanks, and flushed with Tank V3 water.

Figure 5 shows the vent system configuration during the retrieval of V-9. Tank V-9 is the worse case as it has the highest VOCs, and the material balance is based on it. The system was balanced by varying the flow with associated pressure drops as a function of flow. Intermediate pressures were found in reverse from a known zero, e.g., stream 9 in Figure 5, i.e.:

$$P_8 = P_9 + \Delta P_{GAC} \tag{1}$$

The ΔP's for the fans are the static pressures and were modeled within the range as a function of flow in acfm. The summation of the ΔP's must equal zero ($\Sigma \Delta P = 0$) in a leg for balance. This is required to determined the concentrations and determine vent line adequacy. The ΔP's are provided in Table 7.

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The outside air will flow in through a 1 ft diameter opening and out through a side pipe of 6 in diameter. Based on the system balance, the flow in exceeds the 125 ft/min standard. The V-Tanks will be retrieved one-at-a-time such that the others will be valved out as shown in the P&ID (see Figure 9). The other V-Tank systems are similar however there may need to be additional air openings during retrieval depending on the amount of in-leakage from the seals around the retrieval ports. The air from the V-Tanks is mixed with the consolidation ventilation and is heated to reduce the relative humidity (RH). The air then enters a HEPA/VAC system that provides suction and HEPA filtration. The filtered air is then sent to the sulfur-impregnated, granular activated carbon system (S-GAC) to remove VOCs and mercury (Hg).

The concentrations shown in Figure 5 were determined in Appendix A. It was assumed that the initial gas concentrations are in equilibrium with the V-9 PCE, TCA, TCE, and Hg liquid concentrations and decrease rapidly thereafter as a result of the large air influx. The amount of VOC collected during consolidation is expected to be small compared to sparging, on the order of two kg. The consolidation tank concentrations are assumed to stay at equilibrium at the leakage rate of 1 scfm.

Table 7. Gas System Pressure Drops

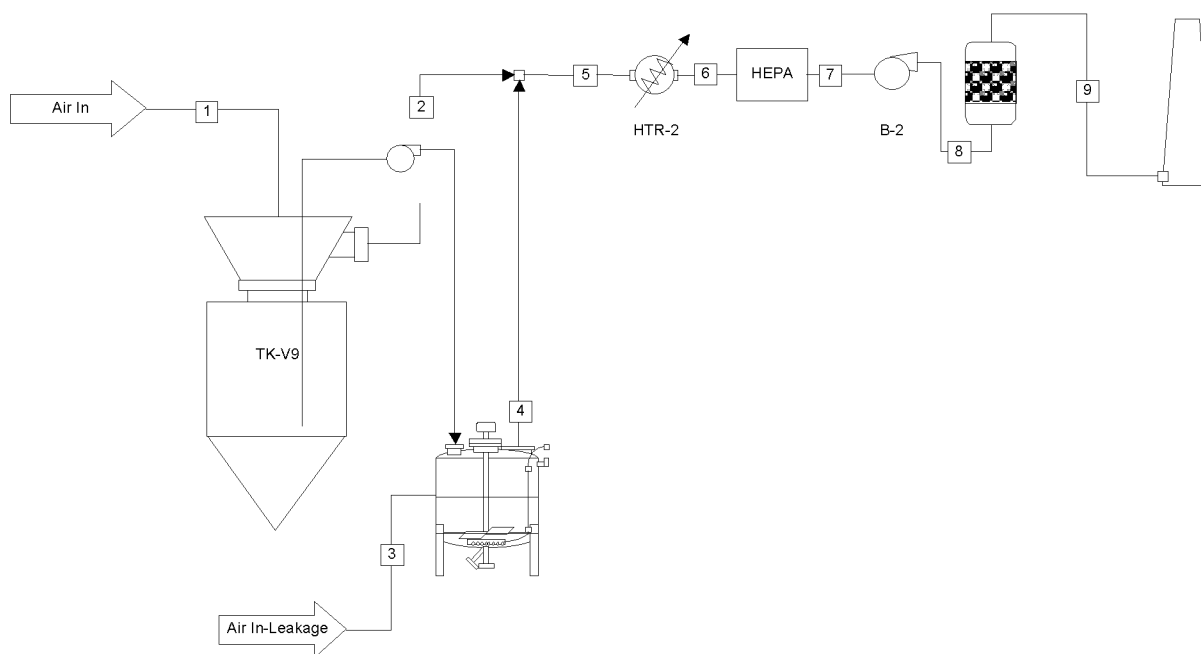| Unit	ΔP, in. W.C.	Notes
Heater	$2.22 \times 10^{-5}Q^2$	Q in scfm
HEPA	$1.11 \times 10^{-5}Q^2$	Q in scfm
Fan	$-0.00002Q^2 + 0.00009Q + 6.865$	Q in acfm
GAC	$0.00003831Q^2 + 0.015Q + 0.074$	Q in scfm
Scrubber	$-0.1903Q + 11.995$	Q in scfm
Dampers	Adjustable	

Figure 5. Gas Treatment Schematic, Consolidation.

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Table 8. Consolidation Material and Energy Balance.[g]

Stream	1 Outside Air in To V9			2 Air out V9			3 In-Leakage			4 Consolidation TK Out			5 Mixed Air		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	100.00	30.00	-30.00	130.00	100.00	-30.00	100.00	70.00	50.00	130.00	70.00	50.00	130.00	99.43	-30.00
Flow, scfm	191.00	155.50	0.00	191.00	155.50	0.00	3.00	3.00	0.00	3.00	3.00	0.00	194.00	158.50	0.00
Flow, acfm	255.76	182.20	0.00	270.24	208.83	0.00	4.02	3.80	0.00	4.24	3.81	0.00	274.49	212.64	0.00
Rate, lb/min	15.43	12.56	0.00	15.43	12.56	0.00	0.24	0.24	0.00	0.24	0.24	0.00	15.67	12.80	0.00
P, in H2O	0.00	0.00	0.00	-1.00	-1.00	0.00	0.00	0.00	0.00	-1.00	-1.00	0.00	-1.00	-1.00	0.00
RH, %	80.00	40.00	0.00	100.00	100.00	0.00	80.00	40.00	0.00	100.00	100.00	0.00	100.00	100.00	0.00
Density, lb/ft³	0.06	0.07	0.08	0.06	0.06	0.08	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.06	0.08
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppmv	0.00	0.00	0.00	4600.00	1.47	0.00	0.00	0.00	0.00	4600.00	4600.00	0.00	4600.00	72.58	0.00
TCA, ppmv	0.00	0.00	0.00	17800.00	5.39	0.00	0.00	0.00	0.00	17800.00	17800.00	0.00	17800.00	280.56	0.00
TCE, ppmv	0.00	0.00	0.00	37800.00	13.20	0.00	0.00	0.00	0.00	37800.00	37800.00	0.00	37800.00	597.53	0.00
Hg, mg/m³	0.00	0.00	0.00	175.00	0.06	0.00	0.00	0.00	0.00	175.00	175.00	0.00	175.00	2.77	0.00

Stream	Heater Output			HEPA Output			Blower Output			S-GAC Output		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	140.00	109.43	-20.00	140.00	109.43	-20.00	140.00	109.43	-20.00	140.00	109.43	-20.00
Flow, scfm	194.00	158.50	0.00	194.00	158.50	0.00	194.00	158.50	0.00	97.00	79.25	0.00
Flow, acfm	279.82	217.09	0.00	281.18	218.39	0.00	276.86	214.65	0.00	139.17	107.91	0.00
Rate, lb/min	15.67	12.80	0.00	15.67	12.80	0.00	15.67	12.80	0.00	7.84	6.40	0.00
P, in H2O	-1.83	-2.02	0.00	-3.51	-4.07	0.00	1.85	1.89	0.00	0.00	0.00	0.00
RH, %	80.00	80.00	0.00	80.00	80.00	0.00	80.00	80.00	0.00	80.00	80.00	0.00
Density, lb/ft³	0.06	0.06	0.08	0.06	0.06	0.08	0.06	0.06	0.08	0.06	0.06	0.08
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppmv	4600.00	72.58	0.00	4600.00	72.58	0.00	4600.00	72.58	0.00	23.00	0.36	0.00
TCA, ppmv	17800.00	280.56	0.00	17800.00	280.56	0.00	17800.00	280.56	0.00	89.00	1.40	0.00
TCE, ppmv	37800.00	597.53	0.00	37800.00	597.53	0.00	37800.00	597.53	0.00	189.00	2.99	0.00
Hg, mg/m³	175.00	2.77	0.00	175.00	2.77	0.00	175.00	2.77	0.00	0.88	0.0138	0.00

g. Weather conditions including temperature and humidity can vary considerably and that these values are rough estimates.

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5.2.2   Sparging

Initially, there will be supernatant from Tank-V3 in one tank and mainly sludge in another. The consolidation tanks will be equalized prior to sparging. The two tanks will be sparged consecutively for 42 hr each at approximately 40 scfm to remove 99% or more of the total mass of all VOCs and most of the volatile mercury in each tank. This process is shown in Figure 6 with a material and energy balance in Table 9. The flows and pressures were balanced as discussed above in consolidation. However, there are some differences. The scrubber is used to treat the sparge air first for particulate radionuclides. Also, there is a bleed air leg that is designed to prevent condensation. This air is heated and mixed with the scrubber air that is 100% RH at 120°F. This mixed air is further heated. As shown in Figure 6, the bleed air has a HEPA/VAC similar to the main leg but this is expected to be un-energized. The damper downstream from the scrubber needs to be adjusted to obtain a fairly substantial pressure drop as the scrubber induces a draft pressure according to the vendors. This damper is considered critical to balance the system. There is also a second HEPA/VAC that will be valved in for the sparging operations.[h]
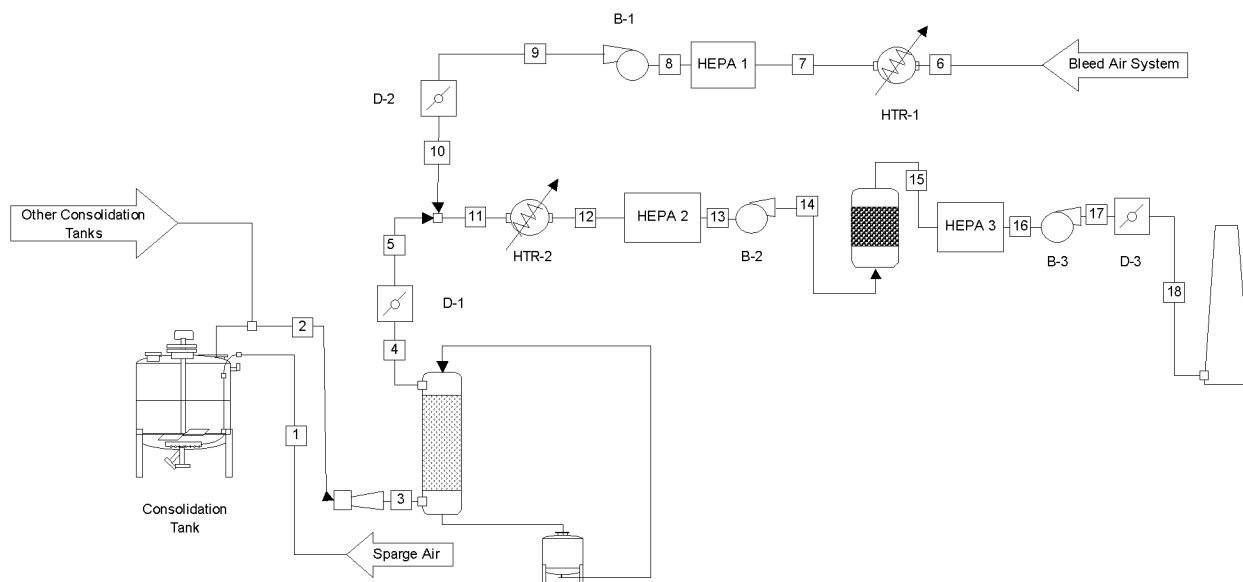

Figure 6. Gas Treatment Schematic, Sparging.

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h. The scrubber operating temperature was provide by the vendor, Severn Trent, 120°F based on scrubbing offgas from the Fenton process that is at a higher temperature. While it is believed that the temperature for sparging will be less, the higher temperature has been retained.

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Table 9. Sparging Material Balance.

Stream	1 Sparge air to C-Tank			2 Air out C-Tank			3 Venturi Outlet			4 Scrubber Outlet			5 Damper 1 Outlet		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	100.00	50.00	-30.00	100.00	50.00	-30.00	100.00	50.00	-30.00	120.00	120.00	120.00	120.00	120.00	120.00
Flow, scfm	40.00	40.00	0.00	40	40	0.00	40.00	40.00	0.00	40	40	0.00	40	40	0.00
Flow, acfm	7.24	6.59	0.00	53.72	48.92	0.00	53.72	48.92	0.00	54.94	54.94	0.00	56.04	56.05	0.00
Rate, lb/min	3.23	3.23	0.00	3.23	3.23	0.00	3.23	3.23	0.00	3.23	3.23	0.00	3.23	3.23	0.00
P, in H2O	2217.09	2217.09	2217.09	-1.00	-1.00	-1.00	3.38	3.38	3.38	3.38	3.38	3.38	-3.48	-3.55	-3.55
RH, %	80.00	40.00	0.00	100.00	100.00	0.00	100.00	100.00	0.00	100.00	100.00	0.00	100.00	100.00	0.00
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppm$_v$	0.00	0.00	0.00	2680.00	254.00	0.00	2680.00	254.00	0.00	2680.00	254.00	0.00	2680.00	254.00	0.00
TCA, ppm$_v$	0.00	0.00	0.00	1510.00	1430.00	0.00	1510.00	1430.00	0.00	1510.00	1430.00	0.00	1510.00	1430.00	0.00
TCE, ppm$_v$	0.00	0.00	0.00	6370.00	1012.00	0.00	6370.00	1012.00	0.00	6370.00	1012.00	0.00	6370.00	1012.00	0.00
Hg, mg/m^3	0.00	0.00	0.00	4880.00	586.00	0.00	4880.00	586.00	0.00	4880.00	586.00	0.00	4880.00	586.00	0.00

Stream	6 Outside Bleed Air			7 Heated OS Air			8 Cleaned OS Air			9 Blower 1 Outlet			10 Damper 2 Outlet		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	100.00	30.00	-30.00	110.00	40.00	-20.00	110.00	40.00	-20.00	110.00	40.00	-20.00	110.00	40.00	-20.00
Flow, scfm	192.70	195.50	0.00	192.70	195.5	0.00	192.70	195.50	0.00	192.7	195.5	0.00	192.7	195.5	0.00
Flow, acfm	258.79	229.73	0.00	264.04	234.99	0.00	265.31	236.16	0.00	265.31	236.16	0.00	265.31	236.16	0.00
Rate, lb/min	15.57	15.79	0.00	15.57	15.79	0.00	15.57	15.79	0.00	15.57	15.79	0.00	15.57	15.79	0.00
P, in H2O	-1.00	-1.00	-1.00	-1.83	-1.85	-1.85	-3.48	-3.55	-3.55	-3.48	-3.55	-3.55	-3.48	-3.55	-3.55
RH, %	80.00	40.00	0.00	100.76	60.76	0.00	80.00	40.00	0.00	100.00	100.00	0.00	100.00	100.00	0.00
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppm$_v$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TCA, ppm$_v$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TCE, ppm$_v$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg, mg/m^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Table 9. (continued).

Stream	Mixed Air			Heated Mixed Air			HEPA 2 Output			Blower 2 Output			GAC Output		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	111.72	53.59	-30.00	121.72	63.59	-20.00	120.00	50.00	-20.00	120.00	50.00	-20.00	120.00	50.00	-20.00
Flow, scfm	232.70	235.50	0.00	232.70	235.50	0.00	232.70	235.50	0.00	232.70	235.50	0.00	116.35	117.75	0.00
Flow, acfm	321.35	292.21	0.00	328.12	298.97	0.00	329.48	293.33	0.00	324.33	288.98	0.00	163.27	145.49	0.00
Rate, lb/min	18.80	19.02	0.00	18.80	19.02	0.00	18.80	19.02	0.00	18.80	19.02	0.00	9.40	9.51	0.00
P, in H2O	-3.48	-3.55	-3.55	-4.68	-4.78	-4.78	-7.09	-7.24	-7.24	-1.71	-2.14	-2.14	-4.04	-4.51	-4.51
RH, %	80.00	40.00	0.00	162.81	122.81	0.00	60.00	40.00	0.00	60.00	40.00	0.00	60.00	40.00	0.00
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppm$_v$	460.68	43.14	0.00	460.68	43.14	0.00	460.68	43.14	0.00	460.68	43.14	0.00	2.30	0.22	0.00
TCA, ppm$_v$	259.56	242.89	0.00	259.56	242.89	0.00	259.56	242.89	0.00	259.56	242.89	0.00	1.30	1.21	0.00
TCE, ppm$_v$	1094.97	171.89	0.00	1094.97	171.89	0.00	1094.97	171.89	0.00	1094.97	171.89	0.00	5.47	0.86	0.00
Hg, mg/m³	838.85	99.53	0.00	838.85	99.53	0.00	838.85	99.53	0.00	838.85	99.53	0.00	4.19	0.50	0.00

Stream	16 HEPA 3 Output			17 Blower 3 Output			18 Damper 3 Output		
	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
T, °F	120.00	50.00	-20.00	120.00	50.00	-20.00	120.00	50.00	-20.00
Flow, scfm	232.70	235.50	0.00	232.70	235.50	0.00	232.70	235.50	0.00
Flow, acfm	327.12	291.51	0.00	322.73	287.20	0.00	322.73	287.20	0.00
Rate, lb/min	18.80	19.02	0.00	18.80	19.02	0.00	18.80	19.02	0.00
P, in H2O	-4.64	-5.13	-5.13	0.00	0.00	0.00	0.00	0.00	0.00
RH, %	60.00	40.00	0.00	60.00	40.00	0.00	60.00	40.00	0.00
Vapors	Peak	Ave	Min	Peak	Ave	Min	Peak	Ave	Min
PCE, ppm$_v$	460.68	43.14	0.00	460.68	43.14	0.00	460.68	43.14	0.00
TCA, ppm$_v$	259.56	242.89	0.00	259.56	242.89	0.00	259.56	242.89	0.00
TCE, ppm$_v$	1094.97	171.89	0.00	1094.97	171.89	0.00	1094.97	171.89	0.00
Hg, mg/m³	838.85	99.53	0.00	838.85	99.53	0.00	838.85	99.53	0.00

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5.3   Calculations of VOC Concentrations in the Off-gas

- During consolidation tank filling operations, vapors from the liquid will be emitted as part of the vented gas stream from the ventilated V-tanks and from the consolidation tanks. This is a small amount as demonstrated in Appendix A but the amount is dependent on the length of time taken for this operation that is uncertain. The initial V-Tank concentrations are assumed to be in equilibrium with the water phase and fall off thereafter. The concentrations of contaminants in the consolidation tank ventilation air are conservatively assumed to be in equilibrium with the concentrations of those contaminants in the water, according to Henry's Law.

- The rate of VOC mass transfer (from Perry 1984) is used to estimate the VOC concentrations in the consolidation tank sparge air. Since this is a batch air stripping operation, the highest vapor concentration will occur at time zero and decrease thereafter to zero. Only a few of the VOCs, those present at the highest concentrations in the V-Tanks, were considered in the sparging calculations. These were PCE, TCA, TCE, and TCE. TCE was the worst-case VOC of concern as it required the longest sparge time to obtain approximately 99% removal. Calculations in Appendix A show that even TCE is nearly quantitatively stripped from the consolidation tanks by sparging for 42 hours nominal. Based on their much higher volatilities, these are easily removed within the sparge time according to predictions. The target is to reduce the VOCs to less than 6 mg/kg based on a total concentration. Appendix A shows that this can be done less than the 42 hours. The gas concentrations are on the order of 27 ppm for PCE, 15 ppm for TCA, and 32 ppm for TCE when this is achieved.

Table 10 shows the average estimated VOC and Hg concentrations in the off-gas during consolidation and sparging. The raw concentrations in Table 10 indicate the concentrations upstream of where the off-gas from the consolidation tanks is diluted by the V-Tank ventilation air or the bleed in flow control air. The dilute concentrations in Table 10 indicate the concentrations diluted by the V-Tank air or the flow control air. The consolidation air values in Table 10 assume the V-Tank concentrations are zero while the consolidation tanks are at equilibrium with the composite VOCs in Table 3. Sparge air concentrations are averaged over a 42-hour sparge time. The actual VOC and Hg concentrations are time dependent and are far higher at first and are predicted to strip off rapidly as shown in Figure 7.

Table 10. Raw and Dilute Concentrations, Retrieval/Sparge.

	Consolidation		Sparging	
Flow, scfm	7	159	40	233
Temperature, °C	25	25	25	25
Humidity (RH)	100	100	100	80
VOCs, ppm$_v$	Raw	Dilute	Raw	Dilute
Benzene	0	0.00	0	0
bromomethane	91	3.85	18	3
Carbon disulfide	0	0.00	0	0
Chlorobenzene	0	0.00	0	0
Chloroethene (vinyl chloride)	65	2.75	86	15
chloromethane	11	0.46	19	3
1,2-dichlorobenzene	159	6.70	32	5
1,3-dichlorobenzene	212	8.93	41	7

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Table 10. (continued).

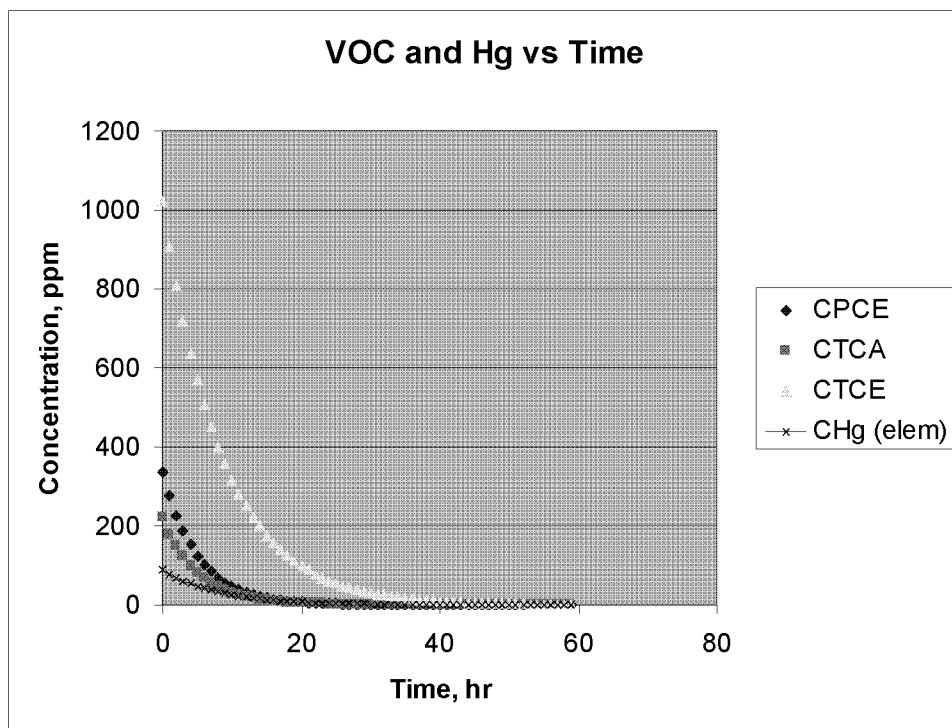|	Consolidation		Sparging	
1,4-dichlorobenzene	69	2.90	43	7
1,1-dichloroethane	67	2.82	14	2
cis-1,2-Dichloroethene	1	0.04	5	1
trans-1,2-dichloroethylene	15	0.64	24	4
1,1-Dichloroethene	2	0.09	5	1
Ethylbenzene	0	0.00	0	0
methylene chloride	44	1.87	77	13
4-Methyl-2-pentanone	0	0.00	0	0
Tetrachloroethylene (PCE)	165	6.94	518	89
Styrene	0	0.00	0	0
1,1,2,2-Tetrachloroethane	0	0.00	0	0
Toluene	0	0.02	6	1
1,2,4-Trichlorobenzene	48	2.04	33	6
1,1,2-Trichloroethane	0	0.01	0	0
1,1,1-Trichloroethane (TCA)	536	22.62	298	51
Trichloroethylene (TCE)	736	31.05	2081	358
xylene	0	0.00	2	0
Hg	3	0.15	2	0.37

Figure 7. VOC vs. Time.

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5.4 System Sizing and Design

5.4.1 GAC Calculations

The GAC sizing is based on removing the entire VOC inventory using a conservative design procedure as described in Appendix A (Army 2001). The worse case isotherm is used specifying a fairly low concentration and using the entire mass of VOCs (56.4 kg). TCA was chosen for this at the average sparging concentration provided in Table 10. Appendix A provides the procedure for this where the TIGG[i] data was quantified and used based on the 95% UCL for TCA[j]. The estimated total loading of VOCs on the carbon is approximately 20% by weight, a reasonable value. Since the sulfur impregnation accounts for 13% of the active sites, the amount of S-GAC needed to be increased accordingly.[k] The number of TIGG, 400 lb units required is three based on the conservative method but the two units are expected to last the duration since the actual humidity will be lower than the isotherm used most of the time. However, it is recommended to have one or two spares.

5.4.2 Scrubber Operations

The scrubber system consists of a venturi scrubber followed by a packed bed designed to remove particulates (e.g., radionuclides). This system is part of the original gas scrubber skid and it was previously decided to use it to reduce radionuclide accumulation on the HEPA filter. Each part, venturi and packed bed, are both expected to have good particulate removal. However, the decontamination factor (DF) is assumed to be 50 for radionuclides except tritium that is assumed to be one for all gas operations. The operation has been qualitatively assessed for removal of VOCs to determine if any recycle problems can occur.

A packed bed scrubber can be modeled as a stage-wise plate system with the liquid descending down from the top contacting the up-flowing gas as shown in Figure 8. The figure illustrates a single-pass liquid whereas the system scrubber is a re-circulating liquid with a high L/G ratio. For a semi-quantitative assessment of the scrubbing tendency of VOCs, the absorption factor is used. An absorption factor greater than one indicates that absorption is possible given enough stages (Treybal 1987). Calculating the absorption factor:

$$A_f = \frac{L}{HG} = \frac{175\,mol/s}{0.4 * 0.6\,mol/s} = 700 \qquad (2)$$

This indicates that the VOCs will scrub (absorb) and accumulate rapidly in the scrubber. Since the scrubber is re-circulating, the concentration shown as x_{Np} and x_0 in Figure 8 will soon be the same such that the VOC concentration in the incoming gas is in equilibrium with VOC concentration in the liquid on the top plate of the scrubber. The radionuclides should slowly build up as discussed in 6. Another way to illustrate this is to consider an imaginary material balance boundary around the consolidation tank during sparging and the scrubber system as shown in Figure 9. Since only dry air is going in, VOC-laden air must be coming out. Near the end of sparging when the sparge air is lean in VOCs, the scrubber will actually become a stripper and will be depleted of the last of the VOCs. However, it should be noted in operations that there will be time delays associated with the scrubber, i.e., there will be hold-up time prior to VOC saturation at which time the scrubber may act like a regulator, keeping the gas concentration more constant than the decreasing concentrations shown in Figure 7.

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i. The S-GAC vendor

j. The TCA and TCE isotherms are very similar
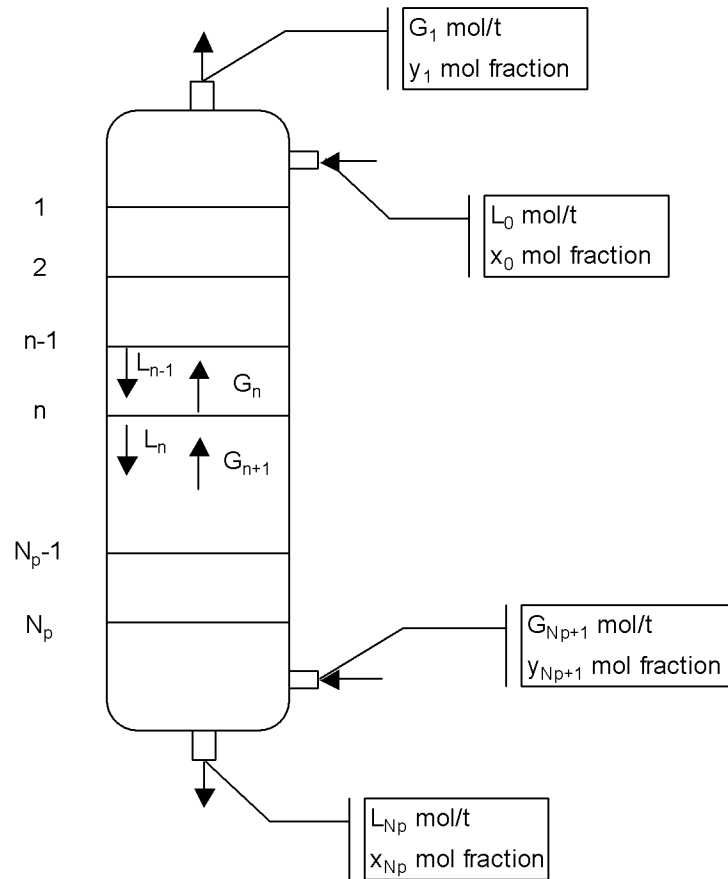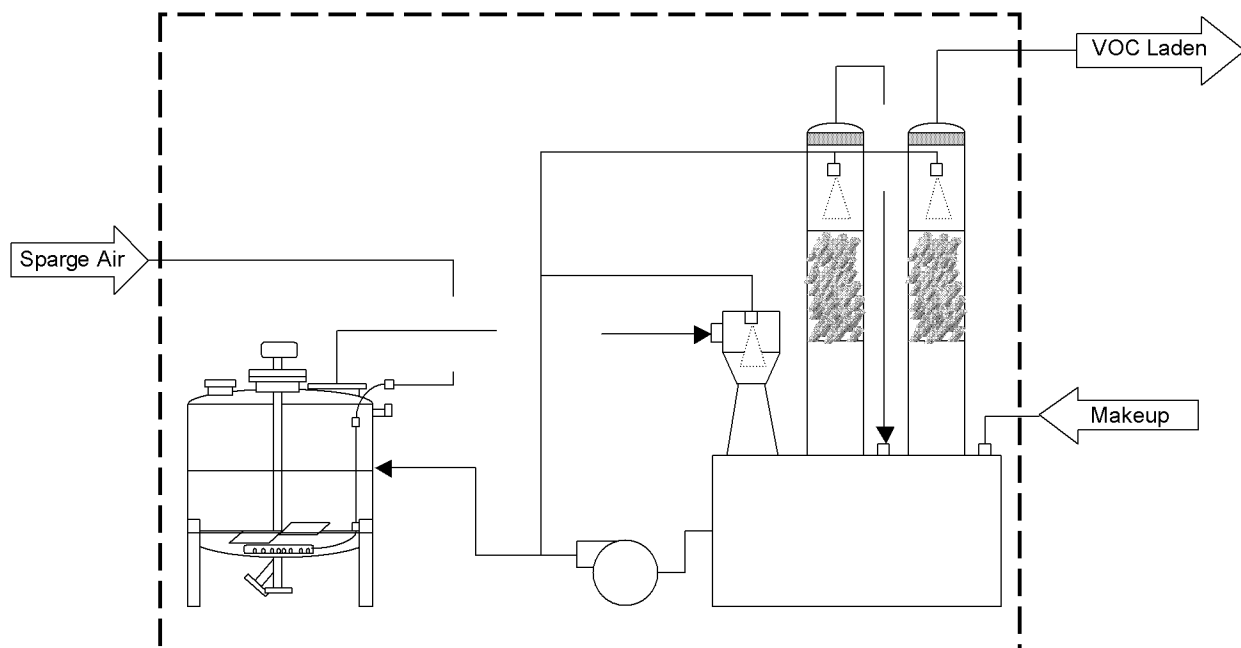
k. wt% sulfur impregnation

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Figure 8. Scrubber Plate Model.

Figure 9. Sparge and Scrubber Balance.

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The vendor (Severn Trent) has stated that the scrubber design is for 10 – 42 scfm. The basis for this is uncertain but the upper limit is likely due to flooding limitations. The scrubber was evaluated to operate at higher flow rates without any water where the packing and demisters would de-entrain a certain amount of aerosol but not to the degree of the system operated wet. The case was evaluated for sparging three consolidation tanks at 40 scfm each, 120 scfm total. The pressure drops discussed previously were used in addition to the two inch pipe from the scrubber and the dry packing based on the 0 gpm/ft^2 curve in Figure 10. As water is increased, the pressure drop increases as shown. The pressure drop for the piping section was found assuming constant density at standard conditions (Bird et al 1960):

$$\Delta P_{pipe} = \frac{32 f(\text{Re}) \rho L Q^2}{\pi^2 D^5 g_c}$$ (3)

Part of the 2-inch pipe section is steel so the ϵ/D was used for steel. Then, the f was modeled by plotting f vs. $1/\text{Re}^{1/4}$ and converted to Q from Re (i.e. Re = $4Q\rho/\pi\mu D$) allowing ΔP to be all in terms of Q.

The additional pressure drops were used along with a flow reduction from the bleed air system with subsequent damper pressure drop to balance the system. However, by operating all three at 40 scfm, the bleed air is reduced to near zero that increases the humidity beyond the design specification for the S-GAC.[1] Therefore, the upper limit of 80 scfm is recommended for this mode. The system could also be operated with less water than design with intermediate benefit and also higher sparge rates. However, the flooding curves would also need to be accounted for. This was done for the packing in Figure 11. The vendor packing flooding curves were converted to specific curves for this scrubber. The power curve equation shown in the plot estimates the upper flooding of 40 scfm at approximately 50 gpm, far greater than the nominal flow given in the scrubber P&ID. The flooding curve along with the pressure drop curves can be used to determine operation for the intermediate cases. However, it is apparent from the curves that the maximum sparge rates would be for dry operations. The HEPA radionuclide accumulation is estimated to be a factor of 10 higher than for the wet scrubber case as discussed in Section 6. Another alternative explored was to use the venturi only with the packing flow blanked off (see the nominal 2 gpm packing flow in the scrubber P&ID).[m] This is essentially the same as operating dry only with the distinct advantage of venturi action for removing particulates.

In practice, the pressure drops and balance equations are approximations. However they should provide a fairly good picture of reality. For operational purposes, it will be more realistic to adjust the flows and dampers to determine what the system will do if higher capacities are desired. This can easily be accomplished via procedure.

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1. 80%RH was used as basis.

m. Valves can be installed in lines to venturi-eductor and packed sections to control separately if desired
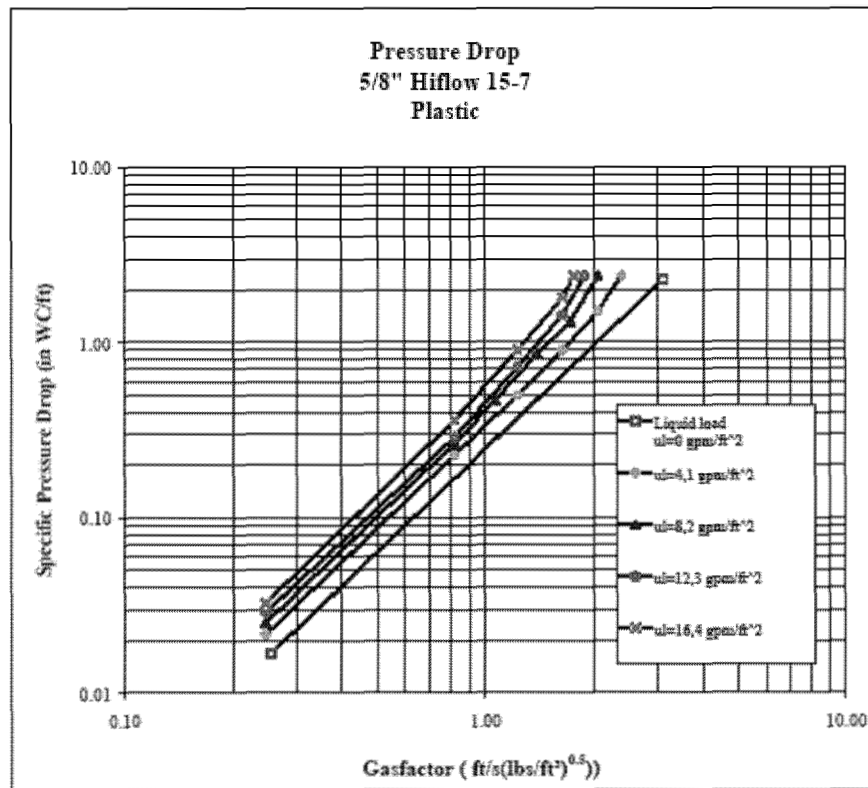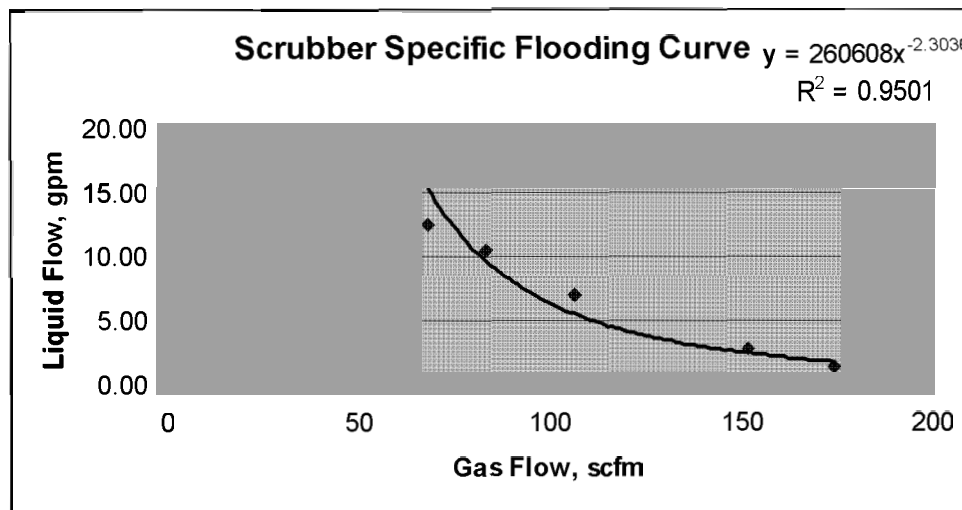
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Figure 10. Packing Pressure Drop.

Figure 11. Packing Flooding Curve.

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5.5   Mechanical Design[n]

5.5.1   P&ID

The P&ID from a process perspective is shown in Figures 12 and 13. This P&ID includes both consolidation and sparging with a future tie-in to Fenton oxidation if required. Most of the system was described above. However, some of the features also include:

- Parallel S-GAC

- Connection for ARA HIC vent

- Various instrumentation; flow, pressure, valving, humidity (RH), DP, temperature

- Compressor for sparge air

- Existing instrumentation (note, this instrumentation is not required for consolidation and sparge)

- Monitoring probes upstream of the GAC and in the stack.

5.5.2   Layout

The equipment layout for the ventilation system incorporates ventilation equipment needed for all three ventilation systems, transfer of V-Tank contents to the Consolidation Tanks, the Consolidation Tank Sparging, and the ex situ Chemical Oxidation/Reduction. All necessary ventilation components were installed so only valve lineups are necessary to switch between ventilation systems, and no contaminated lines need be disconnected to install new or different equipment. The Chemical Oxidation/Reduction skid will not be connected until a later time, and, therefore, a 6 in. pipe cap has been placed on the 6 in. PVC pipe stub where the Chemical Oxidation/Reduction skid ventilation output pipe may be connected at a later time.

Figure 14 is Drawing P-3 and shows the overall V-tank ventilation area. Figure 15 and Figure 16 are Drawings P-11 and P-12 respectively and show all of the ventilation components laid out to scale in the V-tank areas. All components are labeled with a component number and the components are listed in the parts table on Figure 16.

5.5.3   Equipment List

The equipment list for the ventilation system is given in Figure 16.

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n. Not used for final design or construction.

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Figure 12. P&ID (sheet 1).

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Figure 13. P&ID (sheet 2).

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Figure 14. Overall V-tank ventilation area. o

o. Offgas system except for bleed air is outside and sparging is planned for December 2004

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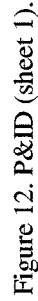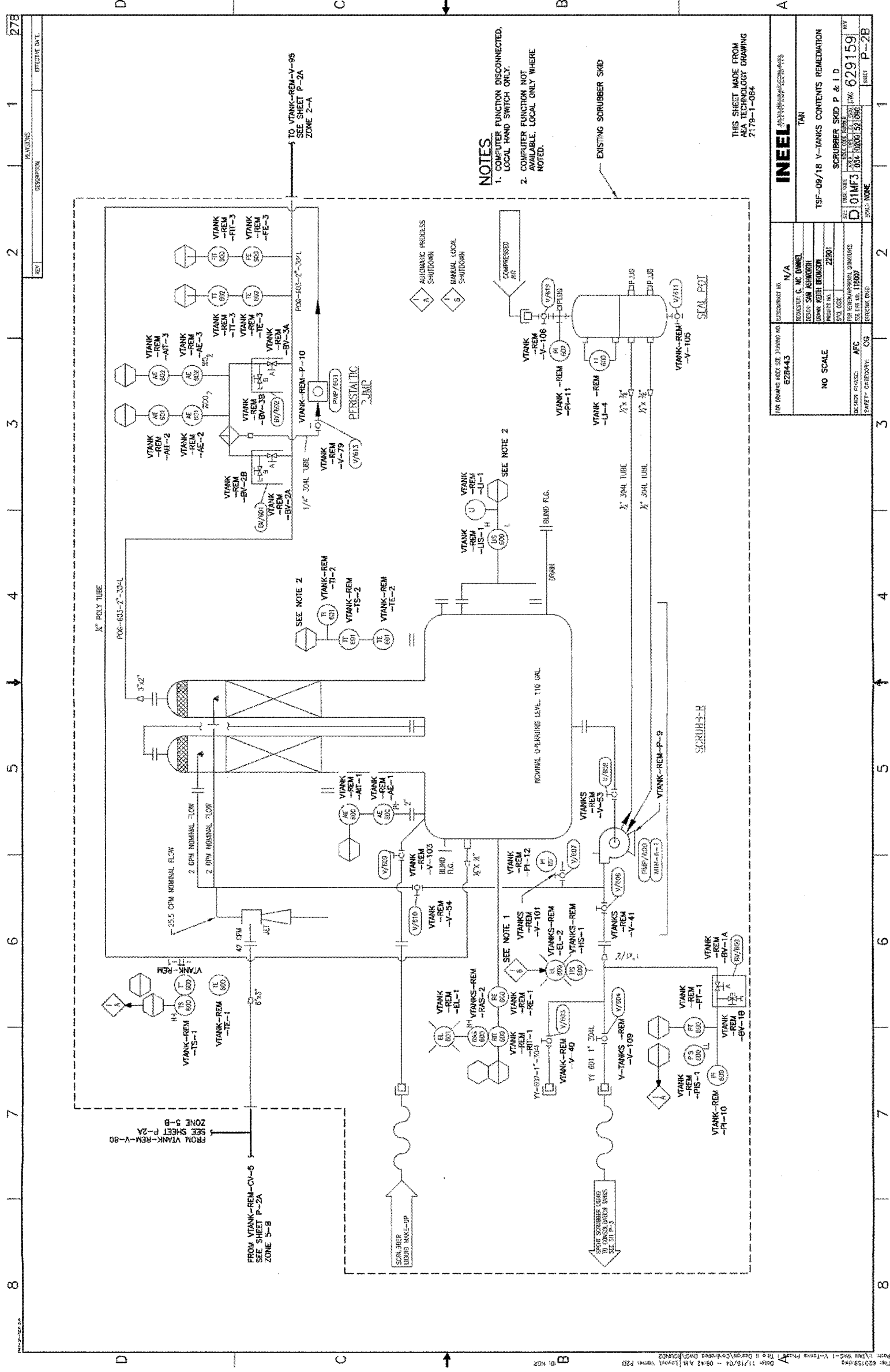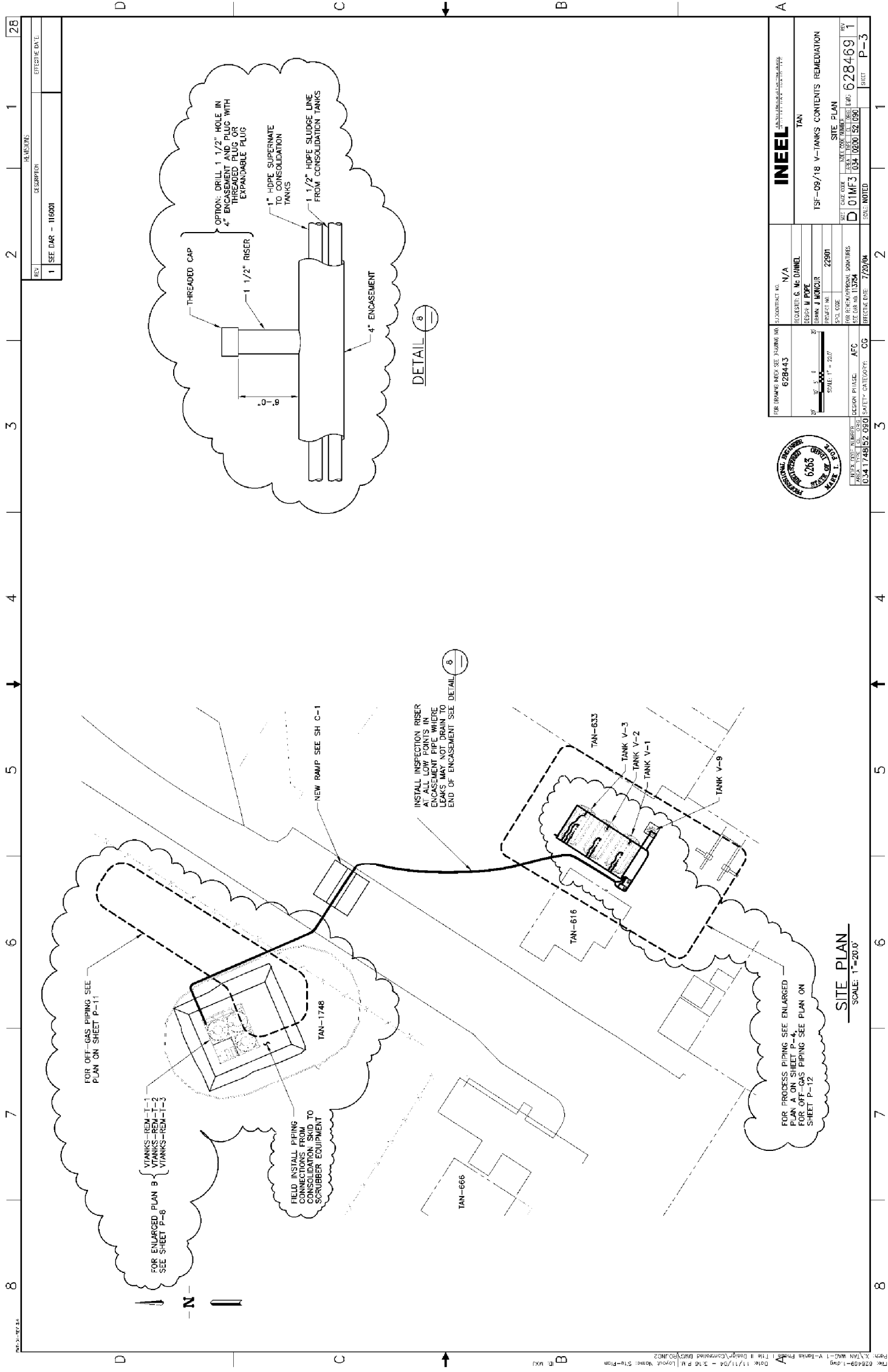
Figure 15. Ventilation components.

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Figure 16. Ventilation components and parts.

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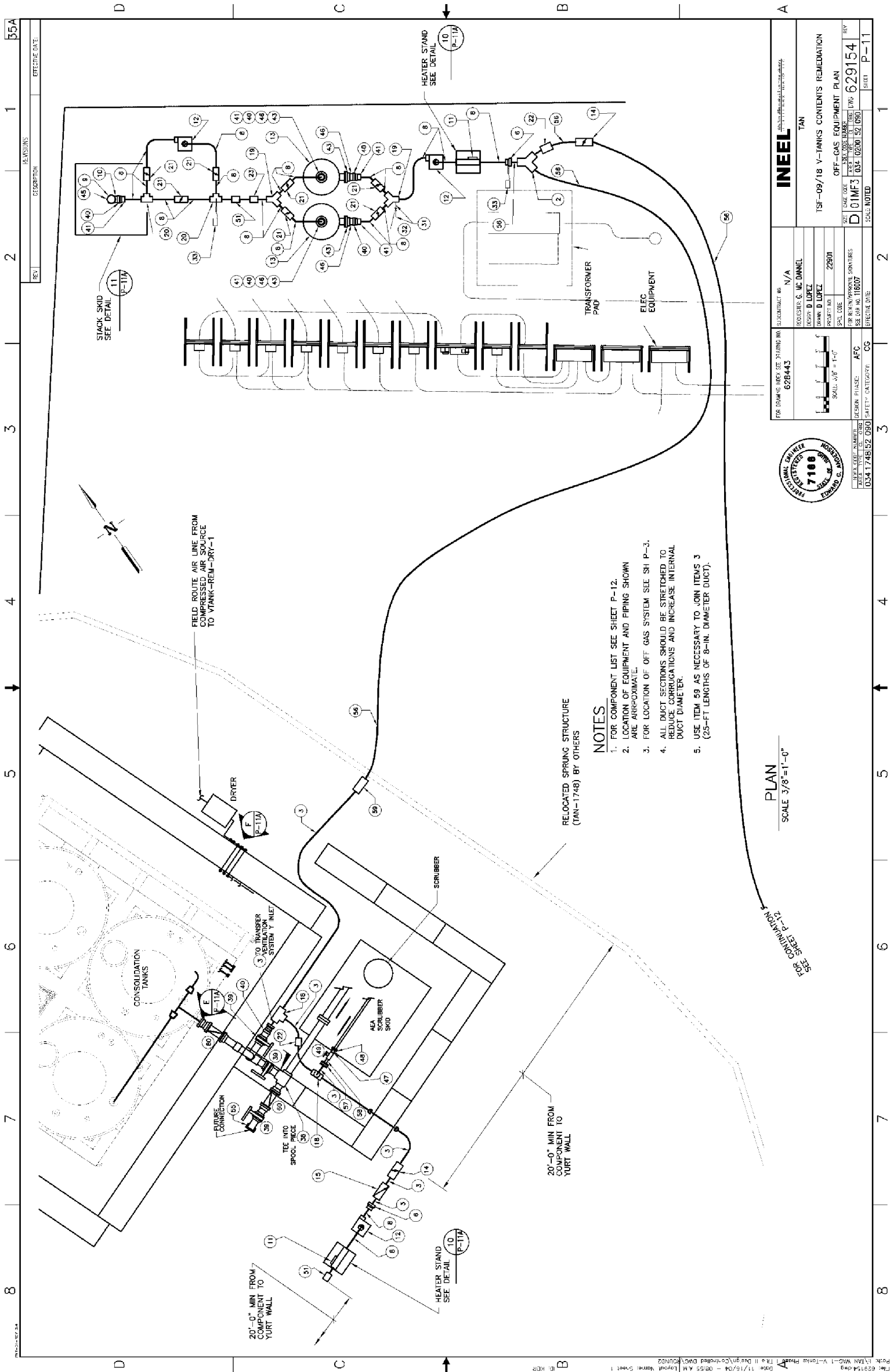
6. RADIONUCLIDE ENTRAINMENT AND BUILDUP

Approximate radionuclide concentrations were determined as discussed in Appendix A. The radionuclides in the gas phase were estimated by determining the amount of radionuclides that would be entrained with water and sludge aerosols using data in Perry's 4th ed. (Perry 1963). The entrainment factor derived from Perry's is in Appendix A, 4.7 x 10^4kg vapor/kg entrained liquid. A flowsheet for these estimates is shown in Table 11. The decontamination factors (DFs) used were 50 for the scrubber, 100 for HEPA 1, 10 for HEPA 2, and 2 for the S-GAC. Accumulation was also estimated for four major radionuclides Co-60, Cs-137, Ni-63, and Sr-90 for the scrubber and the first HEPA based on the DFs. Since tritium was assumed to have a DF = 1 for all equipment, there is no accumulation for it. Accumulation rates for the scrubber and the first HEPA are shown in Figure 17 and Figure 18. The sparging operation assumes good control, i.e., no pressure surge or other transients that would sling large quantities of sludges into the gas phase. If no scrubber were used, there would be more loading on the HEPA as shown in Figure 19.

Table 11. Radionuclide Flowsheet from Sparging.

|	Sparge Tank	Scrubber	HEPA 1	HEPA 2	GAC
Radionuclide	Gas, Ci/L	Gas, Ci/L	Gas, Ci/L	Gas, Ci/L	Gas, Ci/L
Ag-108m	3.52E-15	3.52E-16	3.52E-18	3.52E-19	1.76E-19
Am-241	3.16E-14	3.16E-15	3.16E-17	3.16E-18	1.58E-18
Cm-242	1.34E-16	1.34E-17	1.34E-19	1.34E-20	6.70E-21
Cm-243/244	8.28E-15	8.28E-16	8.28E-18	8.28E-19	4.14E-19
Co-60	1.37E-12	1.37E-13	1.37E-15	1.37E-16	6.86E-17
Cs-134	5.00E-15	5.00E-16	5.00E-18	5.00E-19	2.50E-19
Cs-137	2.56E-11	2.56E-12	2.56E-14	2.56E-15	1.28E-15
Eu-152	6.93E-14	6.93E-15	6.93E-17	6.93E-18	3.47E-18
Eu-154	1.08E-13	1.08E-14	1.08E-16	1.08E-17	5.40E-18
Eu-155	1.22E-14	1.22E-15	1.22E-17	1.22E-18	6.09E-19
Ni-63	3.48E-12	3.48E-13	3.48E-15	3.48E-16	1.74E-16
Np-237	1.12E-16	1.12E-17	1.12E-19	1.12E-20	5.58E-21
Pu-238	5.30E-14	5.30E-15	5.30E-17	5.30E-18	2.65E-18
Pu-239/240	2.96E-14	2.96E-15	2.96E-17	2.96E-18	1.48E-18
Ra-226	8.34E-16	8.34E-17	8.34E-19	8.34E-20	4.17E-20
Sr-90	5.39E-11	5.39E-12	5.39E-14	5.39E-15	2.70E-15
U-233/234	1.82E-14	1.82E-15	1.82E-17	1.82E-18	9.11E-19
U-235	5.85E-16	5.85E-17	5.85E-19	5.85E-20	2.92E-20
U-238	3.15E-16	3.15E-17	3.15E-19	3.15E-20	1.57E-20
Zn-65	6.54E-16	6.54E-17	6.54E-19	6.54E-20	3.27E-20
Tritium	6.25E-13	6.25E-13	6.25E-13	6.25E-13	6.25E-13
Th-228	1.67E-19	1.67E-20	1.67E-22	1.67E-23	8.33E-24
Th-230	6.12E-20	6.12E-21	6.12E-23	6.12E-24	3.06E-24
K-40	1.28E-18	1.28E-19	1.28E-21	1.28E-22	6.40E-23

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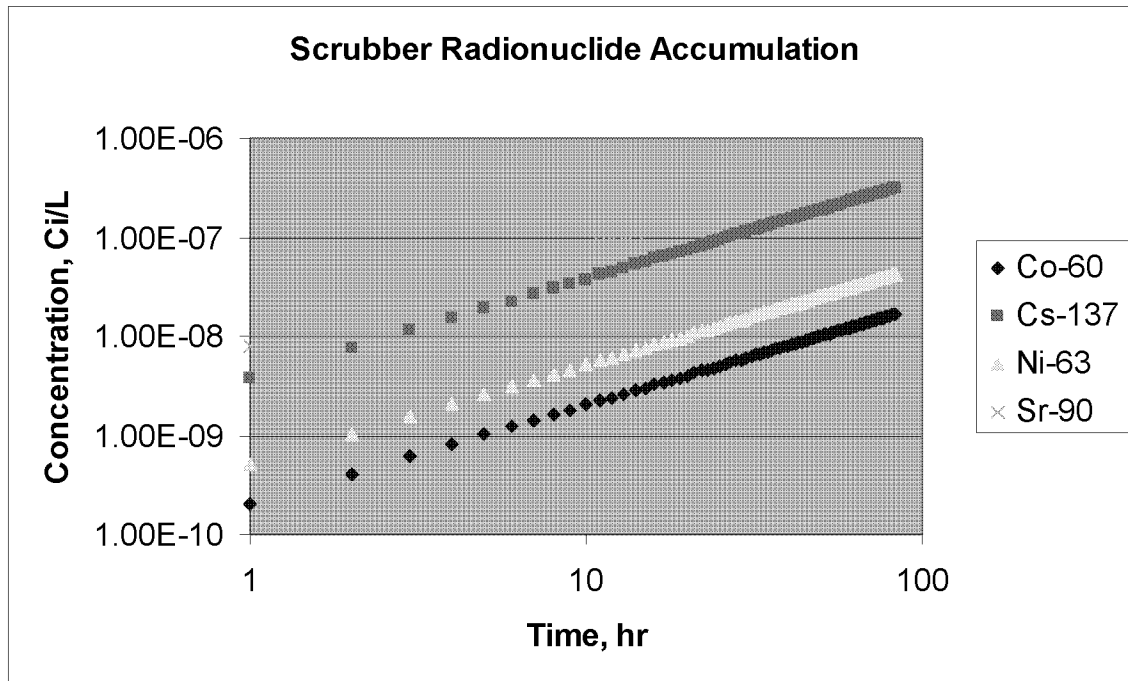
Figure 17. Scrubber Radionuclide Accumulation.
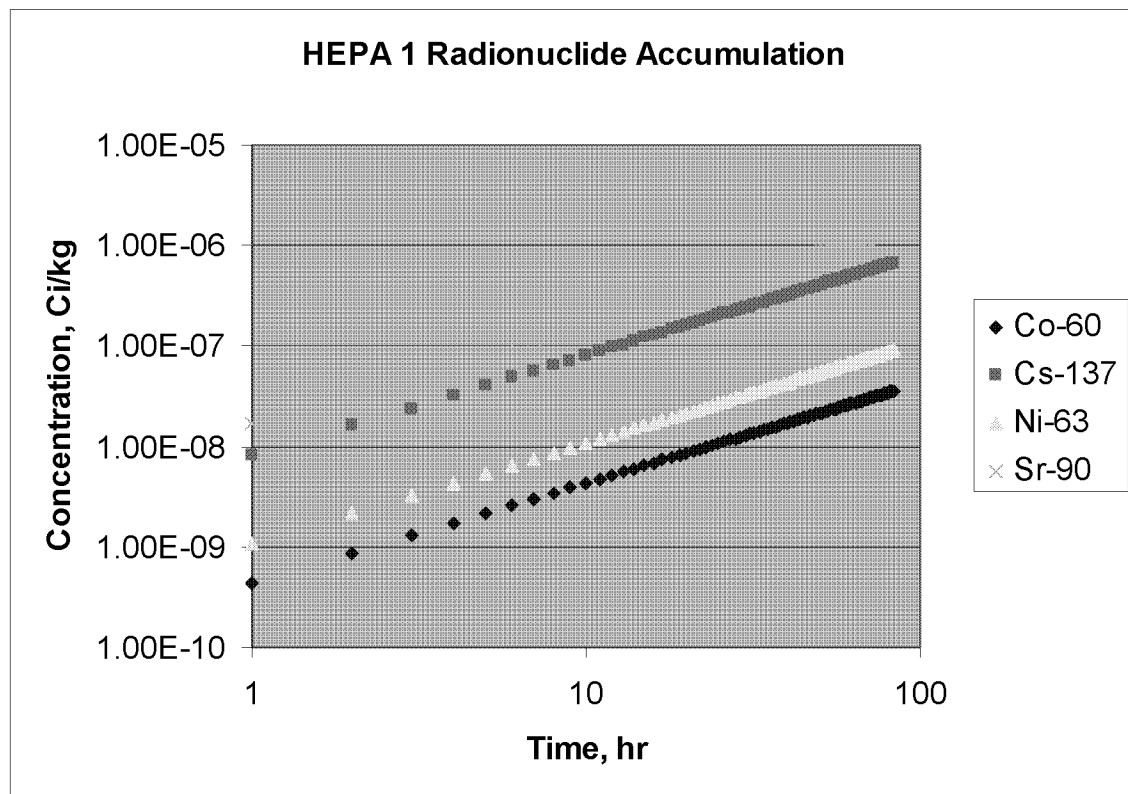
Figure 18. HEPA 1 Radionuclide Accumulation

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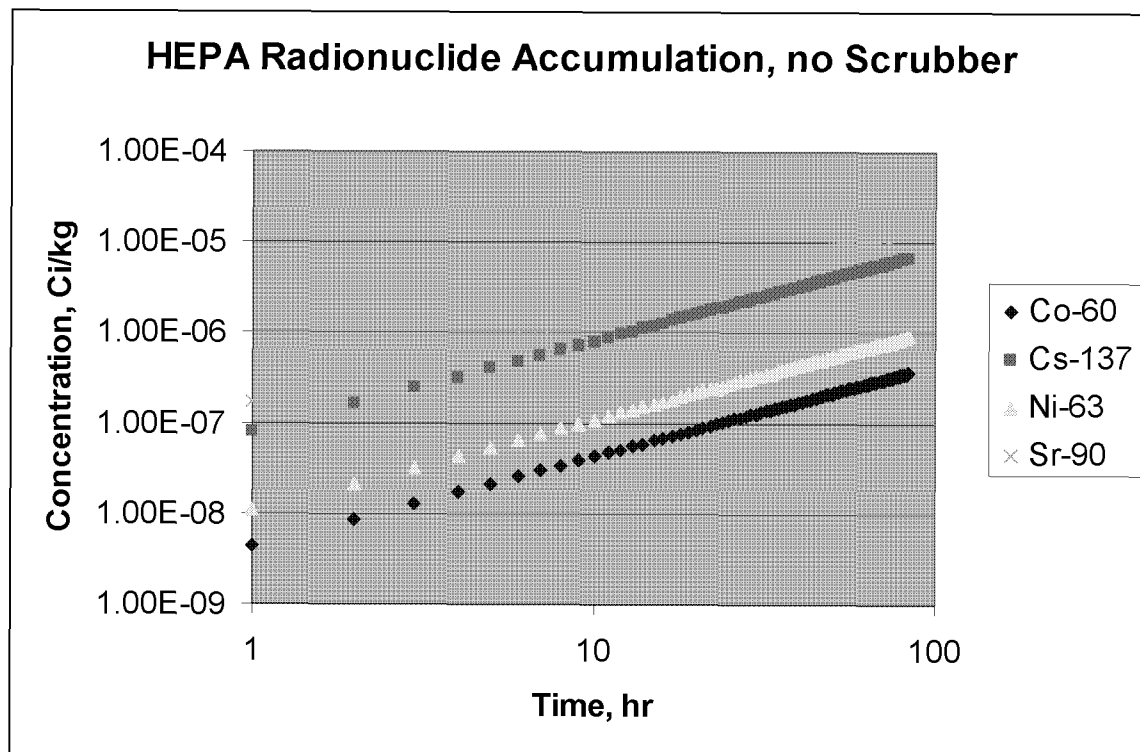
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Figure 19. Radionuclide Accumulation on the HEPA Without a Scrubber

7. ESTIMATED STACK GAS VOC, SVOC, AND HG CONCENTRATIONS,EMISSION RATES, AND MONITORING

The assumed DF for VOCs and Hg on the S-GAC is 200. At these assumed removal efficiencies, stack gas outlet VOC and Hg concentrations are shown in (as the time-weighted average or TWA). The TWA-TLV and other industrial hygiene requirements need to be met for the stripped organics exiting the GAC bed. As shown in Table 12, the TWA-TLV's are easily met without dispersion for PCE, TCA, and TCE at a DF of 200 based on an integral time average. The TWA's were determined from the integral average since the concentrations will be a decreasing function of time as shown in Appendix A. The estimated stack gas concentrations are compared to Industrial Hygiene (IH) limits (TWA-TLV, IDLH, etc.) in Table 12. The estimated stack gas concentrations are less than TWA –TLV values except for the Hg species. However, after accounting for reasonable air dispersion that reduces the stack gas Hg concentration by at least 10x for the nearest receptor (a worker standing 10 ft from a 12 ft stack) the estimated Hg concentration is lower than the Hg TWA-TLV. An Air Permitting Applicability Determination (APAD) (APAD 2003) shows that the remedial action meets the requirements of an air permit exemption, so no air permit is required for the remedial action. The requirements of the air permit exemption are met because, for all VOCs, the stack gas emission rates are less than the IDAPA screening emission limits. Mercury exceeds the APAD values but is still less than the IDAPA screening limit of 0.001 lb/hr. Based on the APAD (APAD 2003) analysis, the regulatory driver is industrial hygiene (IH), i.e., exposure to the on-site worker. Based on the sparging calculations and TWA estimate for mercury, the IH limit of 0.01 mg/m^3 (NIOSH 2003) would be exceeded (0.03 mg/m^3 for allyl-Hg). Therefore, a separate GAC unit to capture mercury would be required. However, dispersion from the 12-ft stack decreases the mercury to below the TWA-TLV for a nearby receptor. This is shown in Table 12 and Appendix A.

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The VOCs and mercury will only be monitored for personnel protection since no monitoring is environmentally required (APAD 2003). Periodic speciated VOC monitoring upstream of the carbon bed. This is done primarily for process control - to determine empirically when the sparging will be relatively complete, and to determine empirically the rate and amount of VOC loading on the carbon. While EDFs have used various estimates and models to determine the amounts and rates of VOC evolution during sparging, the only way to really determine these values, and to determine appropriate sparge times and amounts of sparged VOCs, is to measure them during the process. TIGG Corporation's Breakthrough Indicator is used with the S-GAC units. The indicator is constructed of a clear acrylic tube, capped and diffusion-vented at both ends (see Figure 20). The indicator allows for the air stream to be sampled at a point two-thirds of the way through the units. It provides a visual signal that the bed condition shows free organic or other oxidizable material at that level.

The functional indicator is an oxidizing granular material suspended within the transparent tube. When an oxidizable substance reaches the indicator, a color change from violet to brown/black is clearly visible. A low humidity level (RH <80%) is required in the air or gas being monitored for the oxidation reaction to occur. Most organics and some inorganics will react with the oxidant, irreversibly, at varied rates. Since the indicating material will also react in the presence of ultraviolet radiation, an opaque cover shield is provided. The shield is easily lifted to allow for inspection of the indicator. The breakthrough indicator offers a number of operational advantages. During operation, the air stream is constantly being sampled. The indicator is on passive stand-by until being contacted by some contaminant in the stream. Other advantages are the early warning breakthrough, plus the minimization or elimination of chemical analyses by trained personnel. The Breakthrough Indicator is an economical and effective monitoring system. The indicator is not selective. If a stream contains two or more oxidizable organics with different adsorption potentials, the indicator will react to the organic with the poorest adsorption characteristics. If there is a mixture of organics, and only the better-adsorbed materials are of interest, the indicator will provide a premature or false positive signal of breakthrough.

Figure 20. Breakthrough Indicator.

There will also be periodic monitoring of VOCs and Hg shown upstream of the S-GAC in the gas P&ID. The VOCs will be analyzed by photoionization detector method (PID). UV light ionizes the VOCs that flow through charged plates. The current produced is proportional to the concentration (in ppm) and the signature of the VOC is based on the ionization potential (in eV). The PID is a RAE Systems, MiniRae 2000, 0 –10,000 ppm portable unit with an internal pump. The resolution is 0.1 ppm for the 0-999 range and 1 ppm for the 100-10,000 ppm range. The probe is connected to the monitoring port with a sample withdrawn via the internal pump. It is expected that this periodic monitoring will be approximately every four hours.
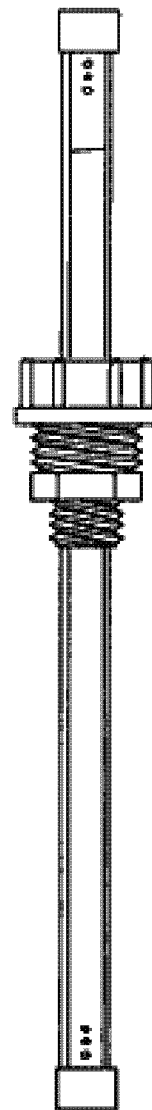
Similar to VOCs, Hg will be periodically monitored upstream of the S-GAC. This will be accomplished using a portable Jerome® 431-X Mercury Vapor Analyzer. The detector element is a vacuum-deposited gold film. Absorption of mercury vapor by this film produces a change in electrical resistance, the time derivative of which is proportional to the concentration of mercury vapor in the vicinity of the detector. The instrument compensates for the fall in detector sensitivity with continued exposure to the vapor. This analyzer also has an internal pump that can be used connected to a port or to draw in from the atmosphere. The range is approximately $0.003 - 1$ mg/m^3. The portable VOC and Hg analyzers can also be used for general area monitoring. Personnel monitoring via individual, units consisting of 3M, 3500 organic passive detection badges that provide a TWA for the VOCs encountered will be assigned as needed by industrial hygiene.

Table 12. Average Concentrations and Emission Rates. [p]

	Maximum	TWA-TLV[a] (calc)	Emission Rate[a] (lb/hr)	TLV	IDLH	15-minute STEL	Ceiling
PCE	2.3 ppm	0.84 ppm	1.41E-3	25 ppm	150 ppm	100 ppm	200 ppm
TCA	1.3 ppm	0.479 ppm	6.36E-4	10 ppm	100 ppm	N/A	N/A
TCE	5.54 ppm	2.87 ppm	4.45E-3	50 ppm	1000 ppm	N/A	100 ppm
Hg[b] (undispersed)	4.24 mg/m^3	1.85 mg/m^3	4.39E-4	0.01 mg/m^3	2 mg/m^3	0.03 mg/m^3	0.04 ppm
Hg[c] (dispersed)	0.00342 mg/m^3	0.00148 mg/m^3	4.09E-4	0.01 mg/m^3	2 mg/m^3	0.03 mg/m^3	0.04 ppm

a. Calculated based on integral average over 42 hours
b. 0.03 mg/m^3 for allyl Hg, the IDLH for allyl is 10 mg/m^3
c. Based on a 20 ft stack and 6 ft tall worker in stack vicinity

8.　SYSTEM SAFETY

There is a need to examine the stability of the S-GAC under the conditions of elevated oxygen concentrations for the Fenton oxidation system flowsheet (if used). This is needed to determine the amount of bleed air required. According to the S-GAC vendor,[q] the stream should be diluted 20:1. However, this was evaluated further for the stability of carbon and sulfur. Appendix A provides the derivation and the results are shown in Figure 21. The results show that the loss rate of the GAC is very small at the temperatures involved at all oxygen concentrations. Also, the reaction with sulfur is expected to result in a similar plot although no kinetic information was found. Discussion with one vendor indicates that their data demonstrates no sulfur-oxygen reactions in the temperature ranges being used (Ashworth 2004c).

Any loss of carbon or sulfur from oxidation at normal operating temperatures is negligible, as calculations show. The only real oxidation issue is: if an area in the carbon bed got hot enough to begin to oxidize, then that area would get even hotter as oxidation progressed. This could eventually result in an carbon bed fire, devolatilization of the VOCs and Hg that were sorbed on the carbon, uncontrolled VOC and Hg emissions and high concentrations, and failure of the carbon bed to efficiently sorb VOCs and Hg from that point on.

Hot spots occur when gas species sorb fast enough so that heat released when species sorb on the carbon is not carried away from that area through convection or conduction fast enough. If that area heats up enough, then carbon or VOCs sorbed on the carbon can start to oxidize to CO and CO_2. This releases even more heat, causing more uncontrollable oxidation, which causes higher temperatures, and more oxidation.

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p. Limits from NIOSH 2003

q. Tigg Corporation

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The most likely times when such hot spots occur are (a) when there are high concentrations of sorbable species (including H_2O), such as at the start of sparging, and (b) when there are higher O_2 levels such as during the Fenton oxidation process.

The best way to avoid carbon bed hot spots and fires is to (a) make process changes like starting the sparging slowly, with initially low sparge rates, (b) maintain some reasonable gas flow through the carbon bed to encourage convection heat transfer, (c) avoid high O_2 concentrations, (d) use a continuous CO monitor downstream of the carbon bed to sense any formation of CO, and (e) upon the detection of CO in the outlet air, stop whatever process was introducing sorbable species to the carbon bed, and (f) purge the carbon bed with an inert gas like N_2 for a short period of time to snuff out any oxidation and simultaneously cool any hot spots.
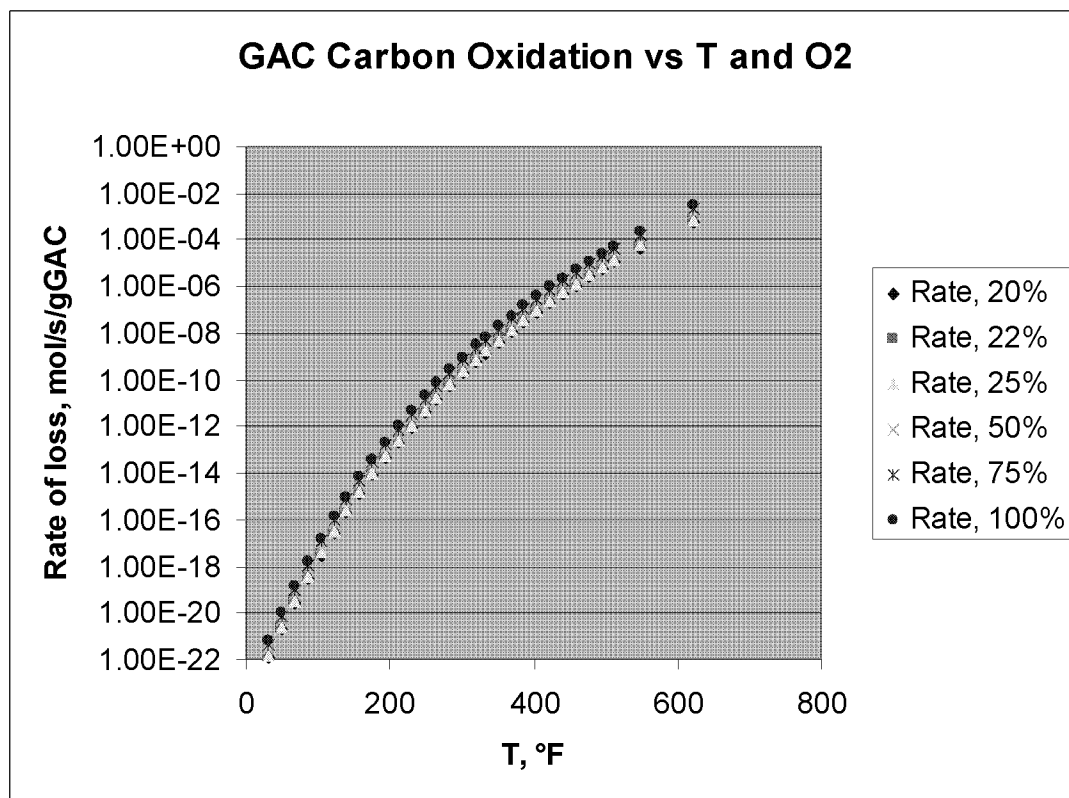

Figure 21. GAC Oxidation.

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10. APPENDICES

Appendix A, Supporting Calculations

Appendix B, Air Stripping of VOCs of Slurries in a Batch Air-Sparged, Agitated Tank

Appendix C, Vendor Information

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